Ministry of Defence

Final Report

Defence Demand for Spectrum:

2008 - 2027

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Issue D

EXECUTIVE SUMMARY

Defence use of spectrum is increasingly challenged by commercial demand

MOD needs spectrum as a key enabler to provide Defence capability both overseas for operational purposes, and in the UK for training, equipment development, and certain operational Military Tasks such as air operations to protect UK airspace through radar surveillance and Quick Reaction Alert fighter aircraft. Over the last 50 years or more, MOD has increasingly introduced new technology that relies on and is enabled by access to spectrum and, in the UK, now has access to approximately 30% of UK spectrum between 100MHz and 3GHz.

In parallel with this, the commercial demand for spectrum to meet needs such as cellular communications has also increased dramatically, and spectrum availability is now recognised as being essential to many areas of economic growth.

HM Government has accepted that public bodies should use spectrum as efficiently as possible and release holdings to the market insofar as possible. With MOD being the largest single public sector user of spectrum in the UK, Defence is actively reviewing its use of spectrum, and planning for future demand. As part of this review MOD has commissioned both this forecast of Defence demand for spectrum in the UK, and an audit of current spectrum allocations. These actions support MODs agreement to produce a 'forward look' on spectrum demand every two years. This study covers 80% of MOD managed spectrum.

We forecast Defence demand for spectrum in the periods 2010, 2015 and 2027.

MOD uses spectrum in the UK to prepare forces in readiness, for defence of the UK, and for some equipment testing purposes. Future demand is driven by Defence strategy, which is based on thinking about likely future global developments. This then leads to requirements for systems which in turn need access to spectrum. So, whilst these requirements do in principle have business cases associated with them, the demand for spectrum is not driven by price in the same way that it may be for commercial applications. This view is confirmed by the analysis we have carried out in this study, which shows a very low elasticity of spectrum demand to price for current equipment.

A further complexity surrounding elasticity of demand is that since frequency bands are typically shared between several MOD users, if spectrum were to be released from one application, it would not necessarily become free since MOD may already be sharing it for other purposes – either for a different type of equipment, or within the same broad type.

Because of this difference in kind to commercial demand, we have adopted a process for this study of understanding demand through discussions on capability and system requirements with users and other stakeholders, and then predicting how much demand is needed to support those system requirements given reasonably efficient spectrum usage. This is a very different approach to the ongoing spectrum audits, which is based on frequencies allocated.

We believe, and precedence exists within commercial demand studies, that extrapolation from such a requirements based approach can form a realistic estimate of consolidated demand. Additionally this approach captures exceptions; unique capabilities, locations, or equipment that is not covered by initial data capture.

Based on this approach of stakeholder interviews, coupled with analysis of trends and technology evolution, we have forecast demand over the time periods 2010, 2015 and 2027.

The picture for 2010 is mixed with some bands having spectrum that could be released

The main area where there appears to be MOD spectrum that is not fully utilised today is in the 3GHz – 6GHz bands. This has partly arisen because the commercial demand for lower frequencies has encouraged release in other bands, and 3GHz – 6GHz has been under less pressure. Whilst there appears to be some excess spectrum available at UHF frequencies we caution against releasing this because of growing demand out through 2015 and beyond.

We show an overall increase in demand for defence spectrum in the UK by 2015

Our findings show increasing demand for spectrum over the period up to 2015, particularly in the VHF / UHF bands, and in bands above 9GHz. These are respectively driven by increased demands for voice and data communications to soldier systems such as used for Network Enabled Capability, and by the introduction of new high performance radar systems.

However, except for a few minor changes, the demand around the main bands of commercial interest (2-4GHz) remains static and our finding indicate some opportunities for reduction in Defence usage in those bands[1]. The bands above 9GHz are of less interest for the high value commercial users (typically cellular network operators) and therefore less contentious.

We see some technologically driven reductions in demand by 2027, but these could be offset by greater capability requirements

The main upcoming technology change affecting spectrum usage is the introduction of new radar systems that will be more efficient in their use of spectrum and which could reduce demand in some bands. Additionally, there is also potential for increased synchronisation of radar systems to improve spectral efficiency. Against this we caution that forecasting capability requirements out to 2027 is very uncertain, and it is possible that any efficiency improvements may be obviated by increased capability requirements.

There is likely to be some small improvement in efficiency of wireless communications systems arising from increased use of ‘intelligent’ radios and more efficient modulation techniques. In our opinion the increased demand for voice and data communications in the VHF / UHF bands is likely to more than take up this increased efficiency, resulting in continued high demand for these bands.

There is considerable potential for regional sharing

In many bands we find that demand for spectrum in neither concentrated in urban areas, nor uniform across the UK. This gives rise to potential for regional sharing of spectrum, with release to commercial operators for urban use where their demand exceeds current civil allocation. This could be a fairly rapid solution to releasing spectrum to the commercial market, without having to re-engineer equipment.

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[1] To be confirmed through detailed study of the systems involved.

Price elasticity of demand is very low

We have analysed a number of existing systems and find that price elasticity of demand for defence spectrum is low, based on the requirements for current capability and systems. We have identified a small number of systems where the cost of spectrum does make it attractive to re-engineer the equipment, subject to being able also to move other systems that may occupy the same band.

In future, the cost of spectrum needs to be included in system design and planning

Whilst the business case for re-engineering existing equipment to reduce spectrum usage is disadvantaged by the cost of that re-engineering, for future systems we believe that cost of spectrum can and should be a driver in efficient design. This needs to be reflected in a new culture of spectrum management within Defence which starts from a perspective of looking at spectrum *needs* rather than merely managing historically available spectrum. This requirements based approach needs to operate at the strategic, long term level, influencing the equipment programme and individual projects within it to balance MOD's demand for and retention of spectrum.

It should be noted that some flexibility will still need to be allowed for, and it should not be assumed that MOD's future requirements can be predicted completely accurately, or that lack of spectrum to undertake a task can be accepted as a 'commercial reality'. Operational requirements change, and MOD is currently wrestling with the divergence between the planned Equipment Programme and systems delivered through Urgent Operational Requirements (UORs). We believe that its is inevitable that the current Equipment Programme will be amended to reflect lessons from current operations.

Finally, as technology determines spectrum occupancy and guides choice of band we have ensured that we have taken technology trends into account in this study. Particular aspects that we have considered have been new options open to Defence, including use of 'Commercial Off-The-Shelf' technologies rather than bespoke military systems, and use of adaptive spectrum allocation to get more usage out of any allocation. Use of commercial technologies will continue to be important for MOD, as it provides opportunities to benefit from improvements in spectral efficiency driven by the aggressive cellular marketplace.

Recommendations

We make a number of recommendations in this report, including a set of band-specific recommendations for each of the twenty bands that we have reviewed. Additionally we make some specific recommendations on ways of encouraging MOD to take spectrum cost into account for future equipment procurement. Specifically we recommend that MOD Integrated Project Teams should consider spectrum in Through Life Cost estimates and that cost should be flowed down to the user in the same way as with other resources.

We recommend that a central role be maintained to ensure optimum spectrum usage across Defence, to minimise the cost of spectrum within the defined capability requirements.

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Appendices

1. OPTIMISING THE ECONOMIC BENEFIT OF MILITARY SPECTRUM USE

1.1 THE ECONOMIC CONTEXT

1.1.1 Spectrum is a key resource for Defence and for economic growth

MOD needs spectrum as a key enabler to provide Defence capability both overseas for operational purposes, and in the UK for training, equipment development, and certain operational Military Tasks such as air operations to protect UK airspace through radar surveillance and Quick Reaction Alert fighter aircraft. Requirements range from basic voice communications systems and data links through to radars used for detection of incoming threats against the UK mainland. Over the last 50 years or more, MOD has increasingly introduced new technology that relies on and is enabled by access to spectrum and, in the UK, now has access to approximately 30% of UK spectrum between 100MHz and 3GHz.

In parallel with this, the commercial demand for spectrum to meet needs such as cellular communications has also increased dramatically, and spectrum availability is now recognised as being essential to many areas of economic growth. A recent report estimated that spectrum underpins around 3% of GDP[2].

This has led to a situation where there is more demand for spectrum than in the past, driving usage to higher frequencies which may be technically less attractive. Various studies have examined this and looked for ways in which the UK can achieve the optimum allocation of spectrum to the competing requirements. In the commercial arena, auctions are known to be a suitable mechanism for allocating spectrum and this has become standard practice for releasing spectrum 'to the market'. However, until recently it has not been possible for public sector spectrum users to allocate in this way since public bodies have not been able to trade spectrum rights with commercial organisations. Public sector bodies have neither the financial freedoms nor the market constraints that exist for the private sector.

1.1.2 Public sector bodies need to use spectrum as efficiently as possible

HM Government has accepted that public bodies should use spectrum as efficiently as possible and release holdings to the market insofar as possible. In 2005 Professor Martin Cave[3] reviewed the public sector's management of spectrum and suggested that there should be some release or sharing of spectrum bands. With MOD being the largest single public sector user of spectrum in the UK, with holdings with a total value estimated at between £55 million and £400 million per annum, that report and its recommendations have had a significant impact on MOD's approach to spectrum management.

The government response to Cave welcomed its results. This included an implementation plan and an undertaking to produce a Forward Look document every two years reviewing progress and reporting on current and future spectrum usage. The first Forward Look[4], in March 2007, included details of MOD's response to the Cave audit.

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2 Ofcom Spectrum Framework Review: http://www.ofcom.org.uk/consult/condocs/sfrps/statement/

3 http://www.spectrumaudit.org.uk/caveaudit.pdf

4 http://www.spectrumaudit.org.uk/pdf/Forward_Look_2007.pdf

In that document MOD reported on progress made by the first phase of the internal audit. This included results indicating the opportunity to share some bands in the 400MHz and 2.7-3.4GHz regions of the spectrum. MOD also undertook to produce a detailed plan for the release of spectrum. However, before doing this MOD needed to take into account not only its current spectrum requirements but also likely future demand.

In order to understand what its specific response should be to this request for release and sharing, MOD initiated this study to examine Defence demand for spectrum in the UK now and over the next 20 years[5].

1.1.3 Spectrum demand arises from capability requirements

Throughout this work we recognise that military demand for spectrum is different to commercial demand, and that we need to lead the study from the military capability requirement. We have therefore considered, through stakeholder discussion, which elements of military capability require spectrum in the UK, and how those capability requirements may change with time. From this we have deduced the demand for spectrum in 2010 and 2015 and, with considerably less precision, out to 2027. The model that we have produced as part of this study incorporates the major drivers of spectrum demand and enables MOD to understand how future equipment deployment or retirement may impact spectrum demand. From this, MOD can understand whether spectrum should be released or acquired, and the overall cost of spectrum to Defence in the UK. So this model fulfils the requirement for a decision making tool and provides an economic model of demand.

1.1.4 MOD does not use exclusively all the bands in which it operates

In assessing demand for spectrum we need to draw the distinction between MOD bands, allocations/assignments, usage and demand:

- MOD bands are the frequency bands that MOD administers (plans for, allocates or assigns frequencies to military users). Ofcom administers civil bands.
- Shared bands: in many cases MOD shares frequency bands with other users – for the purposes of this study we are only concerned with MOD demand in those bands.
- Military allocations/assignments are frequencies that MOD has designated for a particular Defence purpose; these may be partially or fully utilised, or there may be an excess of demand for a particular allocation.
- Usage defines the way in which MOD uses the spectrum today.
- Demand is the spectrum needed by MOD in order to meet its capability requirements.

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5 It should be noted that in parallel with this study, MOD is undertaking an audit of spectrum usage, based on frequency allocations. The fundamental difference between these two approaches is that this study examines, through stakeholder discussions, the current and future spectrum demand from a system perspective; the audit examines currently allocated frequency assignment within existing databases. Additionally, we make certain assumptions about reuse of spectrum that may not be applied in practice.

1.2 MOD SPECTRUM DEMAND IS DETERMINED BY CAPABILITY REQUIREMENTS

MOD's spectrum demand has a Cold War legacy

During the Cold War the UK strategic role within NATO was a requirement to be able to conduct major operations (primarily air based) from UK territories. In the context of a possible war of national survival, MOD's demands for large amounts of spectrum, coupled with significant contingencies to permit frequency agility and other Electronic Surveillance Measures were necessary for the conduct of its primary military task, i.e. the defence of the UK within the context of a major war.

The long development and in-service times of military equipment mean that many of the systems in service now and in 2015 have their requirements rooted in this historical context.

Operational scenarios define capabilities required

The need for particular capability is defined by the type of conflict; for example a 'cold-war' scenario requires a very different use of UK spectrum compared with today's capability-based forces with their emphasis on expeditionary operations.

In broad terms MOD requires spectrum for two major outputs, and a number of enabling tasks:

- There are a number of UK based military operations, both ongoing and contingency, These include the air defence of the UK airspace, maintenance of the nuclear deterrent, counter-terrorist operations (including Explosive Ordnance Disposal (EOD)) and support to the Civil Authorities. In many cases these need high assurance spectrum access including the use of alternative frequencies, high power modes, etc.
- However the majority of military activity in UK is driven by the requirement for the Front Line Commands to generate Forces at Readiness, predominantly for expeditionary operations. This output is characterised by the very large number of users (e.g. for a major amphibious exercise), but a somewhat lower level of assurance of access may be acceptable, or a reduced amount of access may be possible compared with 'deployed' mode. For example Rapier air defence batteries may not need to utilise the system's "hot" frequency agile mode whilst conducting training, and Bowman in-barracks training and testing can be carried out using low power.
- Supporting these major outputs are a number of enabling tasks including:
  - Site security, typically requiring Private Mobile Radio equipment (PMR), across numerous sites.
  - Training support functions which use spectrum for safety (e.g. range radars) or instrumentation purposes. Typically such roles can use fixed frequencies, often at predetermined sites.
  - Research and Development (both by Defence and Defence Industry) requires access to spectrum for both instrumentation and testing purposes. However this can frequently be limited to a relatively small number of (and often remote) sites, and can be constrained through technical (e.g. screened chambers) or procedural (e.g. sector blanking) means.

These differing roles need to be reflected in a new culture of spectrum management within Defence which starts from a perspective of looking at spectrum *needs* rather than merely managing historically available spectrum. This requirements based approach needs to operate at the strategic, long term level, influencing the equipment programme and individual projects within it to balance MOD's demand for and retention of spectrum.

The same culture is required at the tactical, day-to-day, and local level, for example managing Bowman frequencies to meet the need for both formation collective training on Salisbury Plain, and in-barracks training and testing in Garrisons.

In future scenarios, doctrine defines need for services

Military Capability is partly delivered through equipment performance and sustainability, which can usually be quantified readily and objectively. Military doctrine is underpinned by the development of capability that leverages technology to improve the quality of information that informs military decisions.

Improved capability has been brought about by steady introduction of new communications and infrastructure programmes, geo-location systems, data transmission and information management processes, and enhanced Surveillance and Target Acquisition. The military demand for data, voice, high bandwidth, range, and information assurance has therefore put significant pressure on exploitation of the electromagnetic spectrum, with key operational rather than financial targets. Network Enabled Capability (NEC), for example, is partly about the coherent integration of sensor networks which in turn has significant implications for spectrum usage.

Whilst demand for spectrum reflects the emergent and prolific use of networked technologies the "traditional" standard and reliable technologies are retained. The physical environment often determines the technology used; for example to deliver strategic inter-theatre communications in a wide range of environments the military relies on a mix of Long Range HF, Satellite, and Fixed networks.

So, with the background of existing and future requirements, in the context of the Defence demand for spectrum for services the changes in military capability can be estimated and a subjective view initially proposed. The big uncertainty is of course the question of what future conflict scenarios will look like, and how they will affect operations in the UK. This then gives rise to the demand for applications that use spectrum in the UK.

Technology determines how services are best delivered

The best way of delivering services to supply MOD capability will be set by equipment and technology trends. As the technology determines spectrum occupancy and guides choice of band we have ensured that we have taken technology trends into account in this study. Particular aspects that we have considered have been new options open to Defence, including use of 'Commercial Off-The-Shelf' (COTS) technologies rather than bespoke military systems, and use of adaptive spectrum allocation to get more usage out of any allocation.

1.3 THE ECONOMICS OF SPECTRUM MANAGEMENT

In the briefing for this study, MOD asked that the work should 'Improve (MOD's) understanding of the Defence demand and potential uses for UK military spectrum from an economic, market and technical perspective'. The following section discusses the key issues involved in the economics of Defence spectrum demand.

Economic drivers of demand have historically been weak

In the past spectrum was used without a need to justify whether this was being done efficiently. There was little concept of applying economic drivers to public sector spectrum demands, for a number of reasons:

- There is no overall price elasticity of demand for MOD (because of trade-offs of ways of meeting capability / external costs etc.)
- Whilst there are, in some circumstances, price elasticities of demand functions for individual applications, these are heavily quantised. For example, it may be operationally impossible to use slightly more or slightly less of the spectrum for a particular application.
- There are many different forces affecting demand, all of which have significant external dependencies (scenarios, capabilities, technologies, new threats etc.)
- It is recognised that Defence demand cannot be predicted on a time-regression basis – there are insufficient data, and too many variables[6]. We may expect to collect additional data in future which will improve the situation, but the fundamental issues above still apply.

Changes in spectrum availability or cost will affect the MOD Equipment Programme

Until the recent past, MOD assumed that spectrum would be essentially 'free' and that any new service would be implemented as far as possible within existing bands; the Equipment Programme (EP) was largely designed on this basis. The implications of assigning value to spectrum will be far-reaching, particularly where MOD wants to use spectrum that is attractive to public cellular or broadcast services. This will mean that MOD needs to rethink the bands it uses and consider the business case for moving equipment to operate in less popular and hence less expensive bands. Spectrum costs should therefore be reflected in Balance of Investment (BOI) studies between capabilities, and in the Combined Operational Effectiveness and Investment Appraisals (COEIA).

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[6] To handle this complexity, we have developed an approach based around a series of 'Demand Building Blocks' (DBBs) to demonstrate localised spectrum demand. We believe, and precedence exists within commercial demand studies, that extrapolation from such DBBs can form a realistic estimate of consolidated demand. For details of this methodology refer to Section 6.

Direct costs of change depend on where equipment is in the CADMID[7] procurement cycle. In early Concept and Assessment, costs may be relatively small, and may simply involve assessing different options and the effect of price on the business case. In Development and Manufacturing, costs may again be limited, providing that a suitable band can be found with characteristics similar to the original (there may be indirect costs as discussed below). However, in-service migration costs will be very high, and may outweigh the value of the spectrum. Since MOD equipment lifetimes are typically 25 years or more, this is likely to dominate many bands over the next 5-10 years. During the final, disposal, phase, the issue will be whether to dispose of spectrum or hold it for another application.

It is also important to recognise that in some cases laws of physics will force the use of certain bands for certain tasks, and that the logistics of change may make it virtually impossible to implement, even where the business case appears sound. For example, changing frequency allocations of equipment currently deployed on operations would be such an operational burden as to make it infeasible, almost whatever the financial analysis showed the benefits might be. Furthermore MOD's room for manoeuvre is limited by international agreements with NATO (which has agreed harmonised bands), and US forces under the Status of Forces Agreement.

In Section 5 of this document we examine these economic issues in more depth, looking at the potential impact of spectrum charges on MOD demand.

1.4 THE SCOPE AND LAYOUT OF THIS REPORT

2010 – 2015: Summary demand for spectrum

In Section 2 of this report we present a summary of defence demand, as currently predicted, in 2010[8] and 2015. These forecasts of demand have been derived through stakeholder interviews and interpretation of their capability and system requirements to equipment and hence spectrum demand.

2010 – 2015: Detailed analysis of demand in each frequency band

In Section 3 we cover each of the agreed bands of interest from approximately 200MHz to 15GHz. The individual band analyses include forecasts of demand in 2010 and 2015, a geographical analysis of usage across the UK, and an analysis of the economic cost (in AIP) to MOD in using these bands. For each band we include a discussion of how spectrum might be released.

Although it may be difficult and not cost effective for MOD to, for example, halve the number of frequencies that it uses, there are large areas of the spectrum that are not used nationally, but only in a relatively small part of the country. A feature of Defence operations in the UK is also that these tend to be away from urban areas. Opportunities for taking advantage of this are discussed in Section 3.

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7 CADMID: Concept, Assessment, Development, Manufacturing, In-service, Disposal

8 Whilst the original brief for this work called for a baseline view of demand in 2008, we have in agreement with MOD modified this to give a baseline in 2010. The reason for this is that it is not reasonably possible to affect demand in 2008, and a number of new systems are being introduced shortly. Moving the baseline to 2010 puts it at the start of a period by which it is possible to effect change.

2027: Demand for spectrum – trends and conclusions

Section 4 covers our view out to 2027, derived from a number of inputs including discussions with Defence stakeholders, equipment manufacturers, R&D centres and views from the team carrying out this work.

Methodology

The methodology that we have used to produce these forecasts of demand is described in Section 5, including a description of the model that we have developed to capture stakeholder inputs, and produce consolidated demand forecasts.

Economic aspects and effect of price

Section 6 covers the economic issues in depth, including a discussion of differences between MOD and commercial economics of spectrum demand, and an outline of the approach we have taken to model economic issues. In addition, this section includes analyses for key application groups that we have defined, considering whether the impact of AIP might be further reduced by re-engineering equipment or using it differently.

Other issues

During the period of this study we have also considered a number of other issues which have arisen. These are discussed as appropriate in Section 7.

Conclusions and recommendations are included as Sections 8 and 9.

2. DEFENCE DEMAND FOR SPECTRUM

2.1 WHAT DOES MOD NEED SPECTRUM FOR?

MOD needs spectrum in the UK to deliver a number of capabilities including defence of the UK and force generation for expeditionary operations. The technical systems that enable these capabilities need spectrum for a variety of applications. In this section we briefly look at the categories of 'spectrum using' equipment that cover the majority of Defence UK spectrum usage in the bands of interest.

Voice and Data Links

A.1 General Purpose Voice and Data Comms

A.2 Tactical Voice and Data Comms

A.3 Air-Ground-Air (AGA) and Air-Air (AA) Comms

A.4 Tactical Trunked Radio

A.5 Tactical Data Links

Navigational Aids

B.1 Airfield Navigation & Surveillance Enablers

B.2 Airborne Navigation Aids

B.3 Maritime Navigation Aids

Defence and Weapons Radars

C.1 Air Surveillance And Control System (ASACS)

C.2 Tactical Surveillance Radar

C.3 Weapon Guidance Radar

C.4 Airborne Detect & Track Radar

C.5 EW Simulation of Red Systems

C.6 Counter-Battery Radar

Other

D.1 Satellite Communications

D.2 Data / Video / Telemetry Links

D.3 Fixed Point-to-Point Microwave Links

D.4 Other Radar

2.1.1 Voice and data links

This category includes:

- All short-range voice communications for operational use (e.g. site security comms, on-ship comms, AGA comms) and tactical use (e.g. Bowman training)
- Tactical trunked radio systems (Ptarmigan, Cormorant, Falcon)
- Tactical data links (e.g. Link 16) other than high rate links for video surveillance which are included in 'Other' (Section 2.1.4).

2.1.2 Navigational aids

This category includes:

- Air and maritime navigational aids, typically using frequencies (and equipment) shared with civil users – e.g. airport traffic control, approach and maritime radars
- Airborne weather radars.

2.1.3 Defence and weapons radars

This category includes:

- Radars for incoming attack warning and missile guidance. An example of the former is Fylingdales, and there are many smaller systems in defence of assets such as ships and bases. The latter are ground-based, ship-based or airborne
- EW simulation at Spadeadam and other smaller EW simulation sites
- Counter-battery radars are also included here.

2.1.4 Other

There are a large number of other systems in use by the military which do not fall into the categories above. These include:

- Satellite communications
- General purpose telemetry links, including those used on aircraft (e.g. ASTOR), UAVs, aerial targets, missile testing, etc
- Fixed point-to-point microwave links, where these are not already provided by commercial suppliers (e.g. BT) in commercial bands
- Other radars, such as range safety radar and specific aerial target radars.

Note that we haven't included industry R&D sites, since they use spectrum on non-interference basis. We have included industry sites which have operational use.

2.2 WHERE DOES DEFENCE DEMAND COME FROM – OVERALL USAGE BY TYPE OF EQUIPMENT

As discussed earlier, Defence demand for spectrum can broadly be split into a number of categories, which are useful in understanding where demand is concentrated. The categories (applications) that we have used here are:

- Voice and data links
- Navigational aids
- Defence and weapons radars
- Other.

In this section we examine demand for spectrum for each of these applications.

In order to understand the demand for spectrum for these different applications we must recognise that frequency reuse is possible across the UK, which means that the total demand for spectrum is less than the sum of all the individual demands of the systems.

2.2.1 Understanding the relative demand from different types of system

Figure 2-1 below shows the relative demand for spectrum across the major categories *in the bands of interest for this study*, to illustrate the main usage patterns. It is clear that radar systems form the dominant demand for spectrum (mainly above 9GHz but also in 2700-3100MHz).

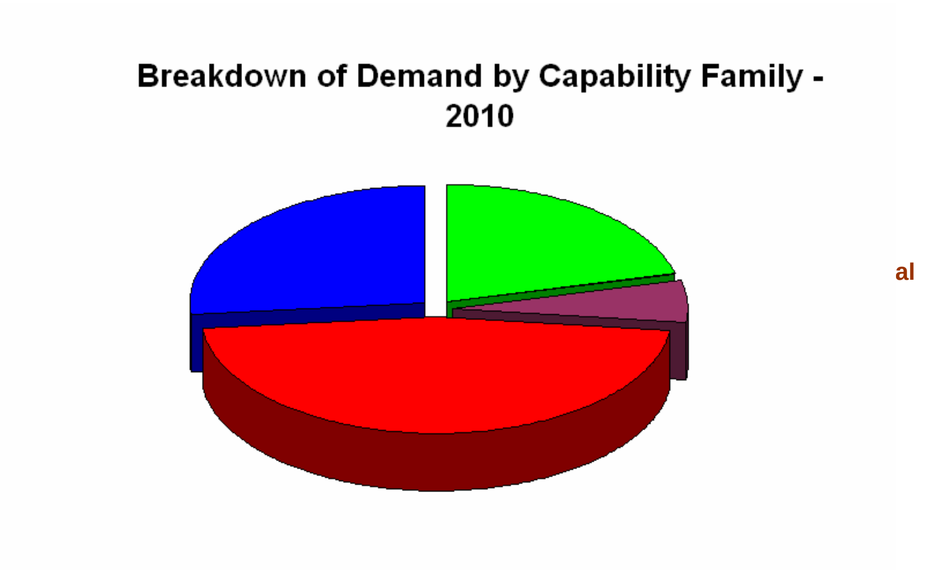


Figure 2-1: Spectrum demand by type of application

In this graph there is approximately 1GHz of 'double-counting' of spectrum usage by systems that share allocations. So where for example data radio systems use the same spectrum as some weapons radar the demand is counted under each type of system. This is one of the complexities of measuring demand for Defence spectrum, in that if spectrum were to be released from one application, it would not necessarily become free since MOD may already be sharing it for other purposes – either in a different type of equipment, or within the same broad type.

Finally, we have cases where different equipments operating in different bands may be used to provide a single capability, for example where two radars are trunked back to a single point. The military capability that this represents requires access to both radars, and hence both frequency bands. Exploiting these bands for other uses therefore poses particular difficulties.

2.2.2 Differentiating between primary and opportunistic users of bands

In most of the MOD administered frequency bands we find a range of systems, some of which have a specific requirement for that band, either for reasons of physics (e.g. radar systems) or for international standardisation (e.g. air / maritime radars, NATO bands). Also, in some cases a single system may be the major occupant of a band and is therefore the defining application within that band. We reference these as 'primary applications'.

There are also a number of systems that could be placed in a range of bands, and which may have been given a particular allocation because the frequency was available. They may occupy a relatively small fraction of the band, or be used in a relatively small geographic area. We refer to these as 'opportunistic applications'.

2.3 FREQUENCY BANDS

2.3.1 Bands of interest

This Study has concentrated on twenty prioritised bands as agreed with MOD, to cover 80% of 'MOD Spectrum'. In prioritising, the following factors were used:

- Administered Incentive Price[9] (economic value) for band
- Ofcom's aspirations for spectrum in demand in the next 15 years
- MOD's perspective on key spectrum to maintain military capability
- Perceived low use bands
- Military Bands where greater spectral efficiency may release band edges.

We are primarily reviewing 20 bands covering over 80% of the value and bandwidth of Defence managed spectrum. These are shown in Figure 2-2 below:

- "Very High" means over £300k / MHz / year
- "High" means £150k to £300k / MHz / year
- "Medium" means £50k to £150k / MHz / year
- "Low" means £5k to £50k / MHz / year.

[9] Administrative Incentive Pricing (AIP) is a proxy for commercial value of a band. It is set by treasury and MOD and other public sector users will pay this cost for spectrum usage.

Band Edges (MHz)		Net width MHz)	AIP per MHz £k)	Total AIP (£)
3100	3400	300.0	Medium	£36m
2700	3100	280.0	High	£67m
3400	3600	120.0	Medium	£14m
230	380	150.0	High	£30m
2310	2390	80.0	High	£19m
4400	5000	600.0	Low	£11m
410	430	16.0	Very High	£6m
430	450	20.0	Very High	£8m
5650	5850	100.0	Low	£2m
380	400	10.0	High	£2m
5300	5650	350.0	Low	£6m
401.5	406.1	6.0	Very High	£2m
8025	8400	375.0	Low	£5m
8500	8750	250.0	Low	£3m
9500	10125	625.0	Low	£5m
14620	15230	610.0	Low	£5m
7250	7400	150.0	Low	£2m
9000	9500	250.0	Low	£2m
13250	13400	150.0	Low	£1m
13400	14000	300.0	Low	£2m

Figure 2-2: Prioritised frequency bands for this study

2.3.2 Other bands

During the course of this work we have gathered data on equipment and usage in other bands; this is included in the 'Equipment Spreadsheet' of the model, although the results are not analysed in detail in this report.

2.4 WHICH APPLICATIONS USE WHICH BANDS

2.4.1 Allocating spectrum to applications

So far we have looked at the relative demand for spectrum across the major system groups used by Defence in the UK. However, recognising that some bands are more attractive than others for particular applications we also need to understand which systems use which bands.

There are a number of points to note in this:

1. As with Figure 2-1, the following charts show demand for applications in isolation, allowing for frequency reuse by systems in that category as we have provided in the model[10].
2. The total spectrum needed for all applications will, in general, be less than the sum of that needed for the individual applications, because reuse between categories may be possible.
3. The demand has been calculated by discussing needs with stakeholders, and has not taken into account any changes that might result from increased rates for spectrum.
4. In shared bands, we have calculated excess usage as being demand over the total band width (where 'total band width' includes spectrum that is used by others), so there may be additional congestion caused by MOD allowing other users to share that band.
5. Similarly, other users in those shared bands may have considerable demand, in excess of the capacity of 'their' part of the band. So a band for which MOD have only light demand may be congested in reality.

The charts included here show the demand for primary applications using MOD bands. As discussed earlier[11], there are other systems that could in principle be allocated alternative spectrum and do not form a significant fraction of the demand in a band - these are designated as opportunistic uses for this report and do not appear in these charts.

The colour-coding in the charts is as follows:

- Green: MOD demand for spectrum, that is met within the Gross width of the band
- Blue: Spectrum which seems to be in excess of MOD demand.
- Pink/Red: MOD demand for spectrum in excess of the Gross width of the band.
- Grey: Excess spectrum over and above the part that MOD pays for.

[10] For description of frequency reuse model see Section 5.5

[11] See Section 2.2.2

2.4.2 Demand for Voice and Data Links

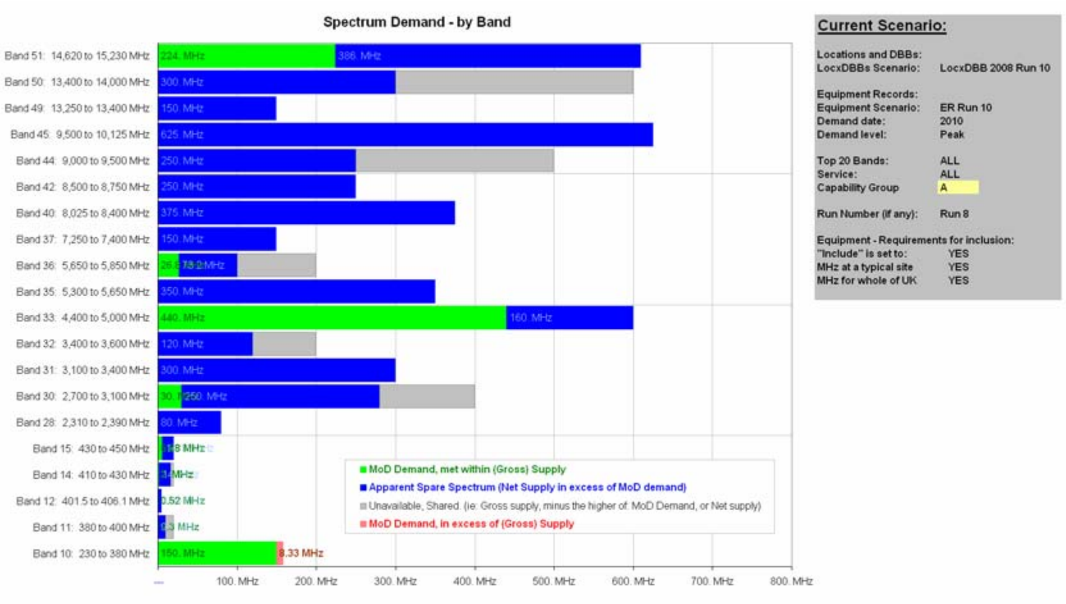


Figure 2-3: Intensity of band usage for Voice and Data Links (2010)

Key Voice and Data systems are trunked radio (Ptarmigan, Cormorant, Falcon), Bowman HCDR, general voice (e.g. PMR, A/G/A, A/A comms) and some special systems.

The only band where Voice and Data links *in isolation* produce excess demand is 230 – 380MHz, where trunked radio systems, Bowman HCDR and various voice systems combine to provide demand in excess of the available capacity. However, the bands from 380MHz to 450MHz have similar characteristics and could largely be grouped together.

Looking forward to 2015, we see that the major changes in demand will come from the introduction of FIST, and Ptarmigan trunked radio going out of service.

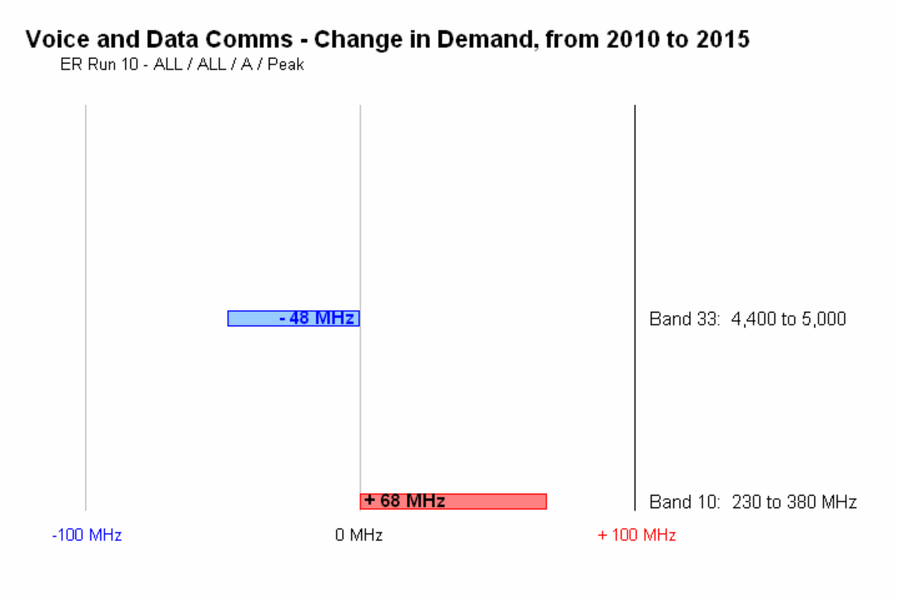


Figure 2-4: Change in band usage for Voice and Data Links (2015)

2.4.3 Demand for Navigational Aids

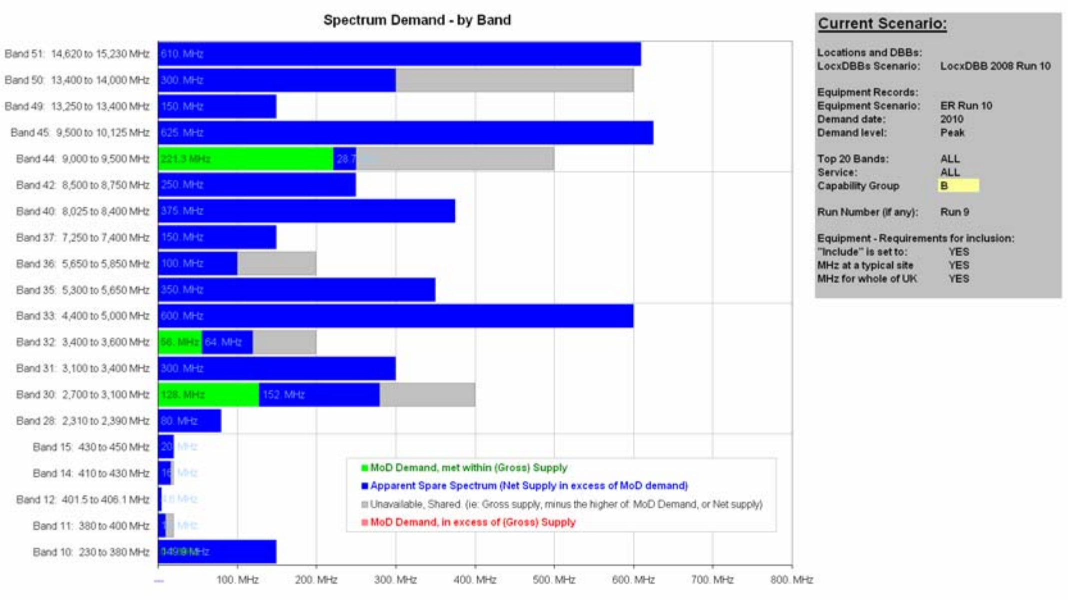


Figure 2-5: Intensity of band usage for Navigational Aids (2010)

Key systems in these bands are Watchman radars, Hercules station keeping equipment, airborne weather radars and naval navigaton radars.

The key bands for these systems are 2700 – 3100MHz and 9000 – 9500MHz.

Looking forward to 2015, we see no significant changes in demand, with a small change in 2700-3100MHz due to some changes in naval radars (as the T45 replaces the T42).

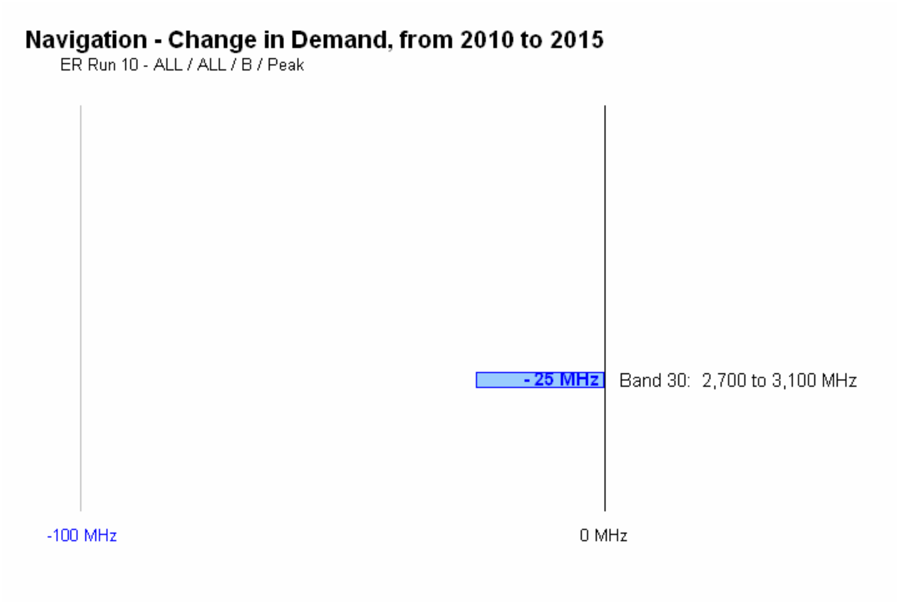


Figure 2-6: Change in band usage for Navigational Aids (2015)

2.4.4 Demand for Defence and Weapons Radars

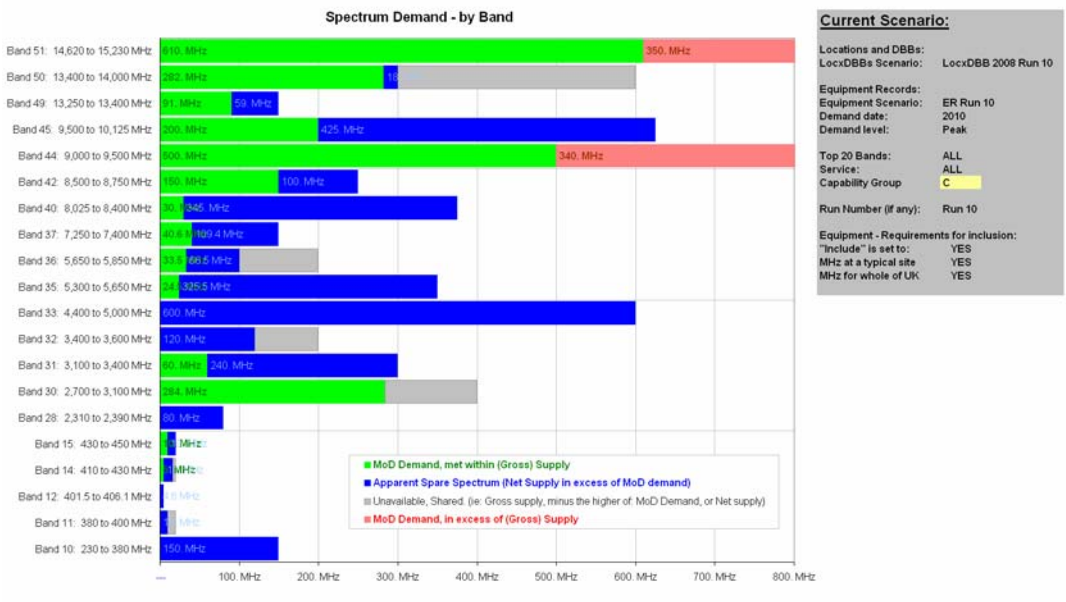


Figure 2-7: Intensity of band usage for Defence and Weapons Radars (2010)

Defence and Weapons radars in these bands are naval (T996, SAMPSON, LRR, T968, T909, T911, Goalkeeper, Seaspray, Blue Kestrel, Phalanx), airborne (Tornado Foxhunter AI24), ASACS (T101, T102, BMEWS Fylingdales), AWAC, Searchwater, counter-battery (COBRA, MAMBA), EW Simulation (e.g. Spadeadam), Meteor missile and Rapier Dagger. The bands where Defence and Weapons radars *in isolation* produce excess demand are 9000 – 9500MHz and 14620 – 15230MHz, but other key bands include 2700 – 3100MHz, 8500 – 8750MHz, 9500 – 10125MHz and 13400 – 14000MHz.

Looking to 2015, we see that major changes in demand will come a changes in naval radars, primarily the T42 destroyers being replaced by T45, JSF (and its radars) replacing the Tornado, and the Meteor missile being deployed operationally.

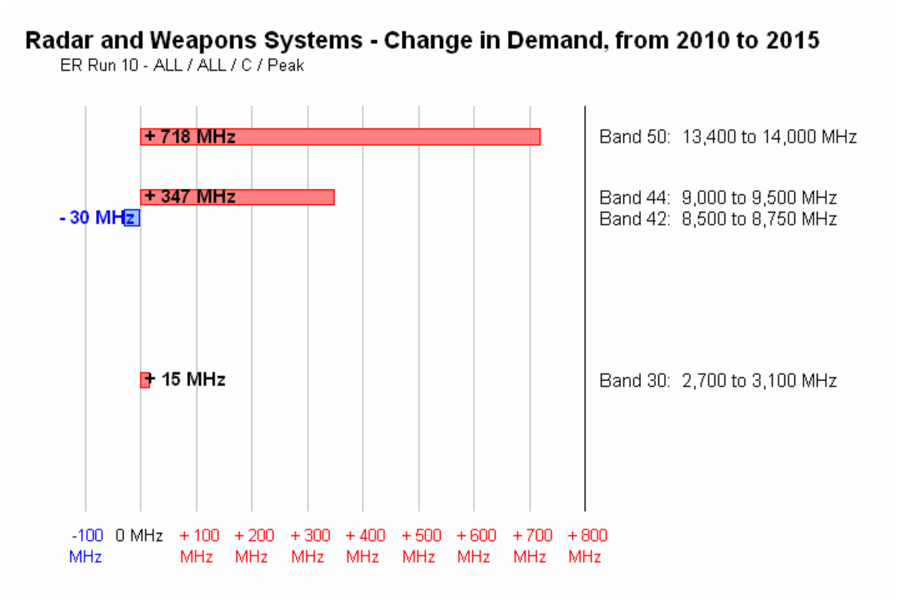


Figure 2-8: Change in band usage for Defence and Weapons Radars (2015)

2.4.5 Demand for Other Applications

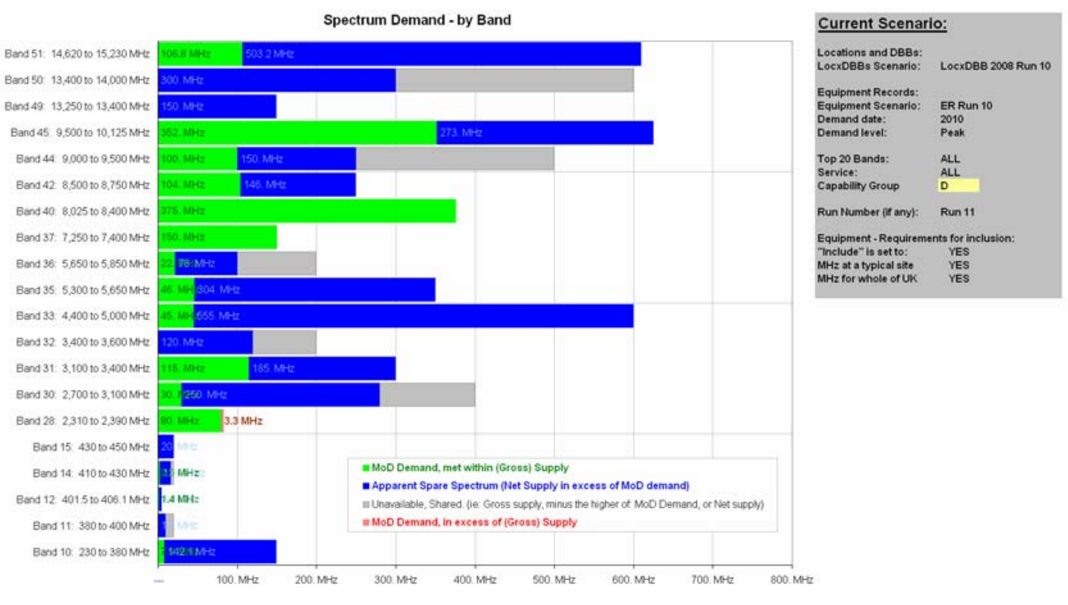


Figure 2-9: Intensity of band usage for Other Applications (2010)

Key systems and applications in these bands are satellite communications, data / video / telemetry links (for manned and unmanned aerial surveillance, UAVs, aerial targets and missiles), range safety radars and aerial target radars.

Key bands include those that form part of the Paradigm bands for satellite communications (7250 – 7400MHz and 8025 – 8400MHz), and those used widely for data / video / telemetry links (2310 – 2390MHz and 8500 – 10125MHz).

Looking forward to 2015, we see that the forecast for demand remain very similar to the 2010 picture.

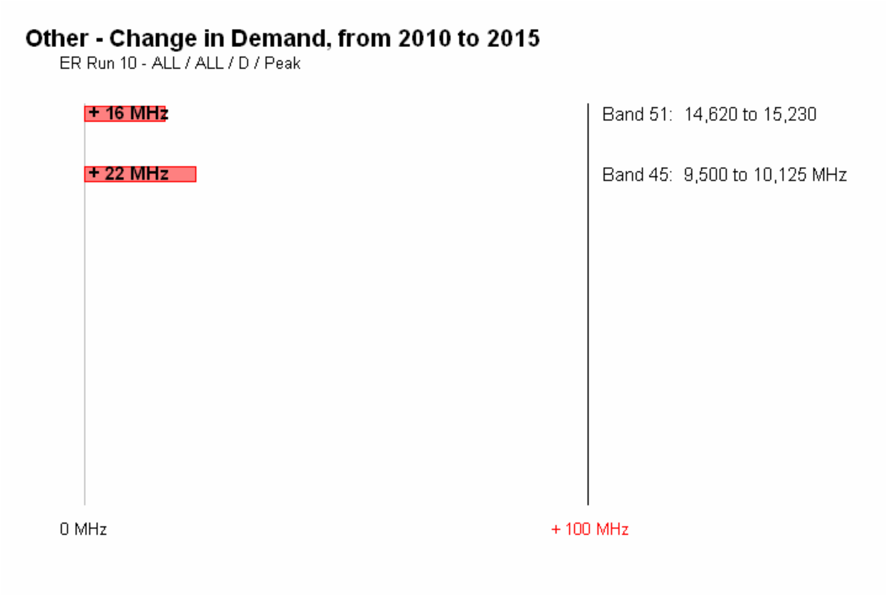


Figure 2-10: Change in band usage for Other Applications (2015)

2.5 WHICH USERS USE WHICH BAND (FLEET, LAND, AIR, OTHER)

2.5.1 AIR

The chart below shows demand by band for 2010. There is heavy demand in the three bands 2310-3400MHz and in 9-10.1GHz, with a spread of systems across other bands.

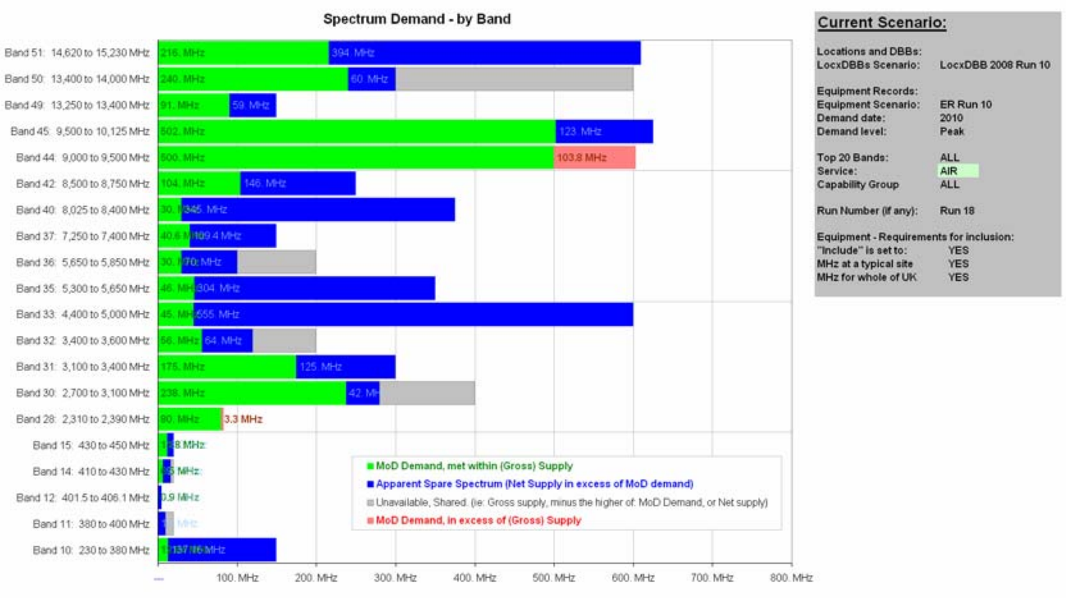


Figure 2-11: Demand for spectrum by band – AIR – 2010

By 2015, there is greater congestion in the band 9-9.5GHz and there is substantial new demand in the band 13.4-14.0GHz. These are due to the introduction of the Joint Strike Fighter and the Meteor missile by 2015.

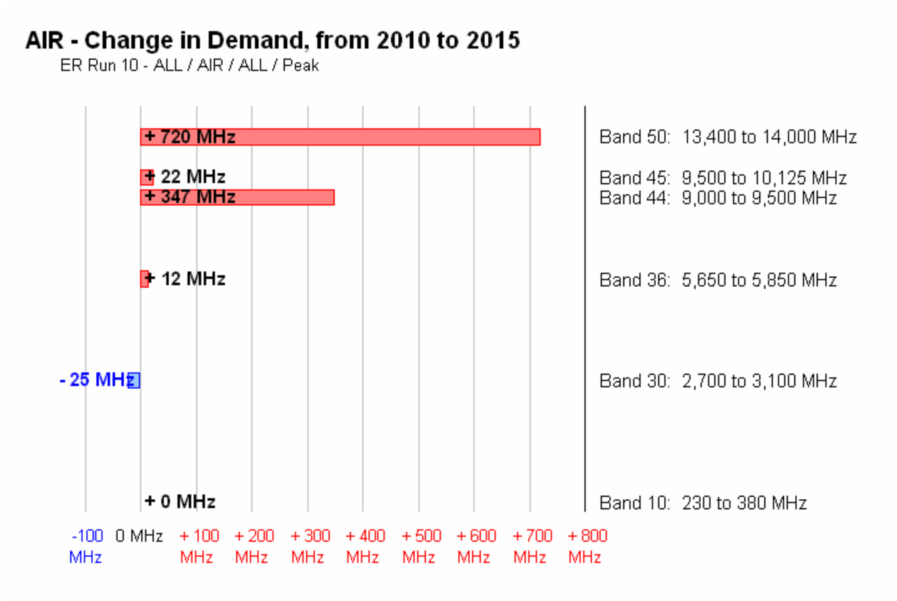


Figure 2-12: Demand for spectrum by band – AIR – 2015

2.5.2 FLEET

Demand is concentrated in five or six bands, with congestion at 15GHz and significant demand in the 9-9.5GHz band. Overall demand is less than that of AIR.

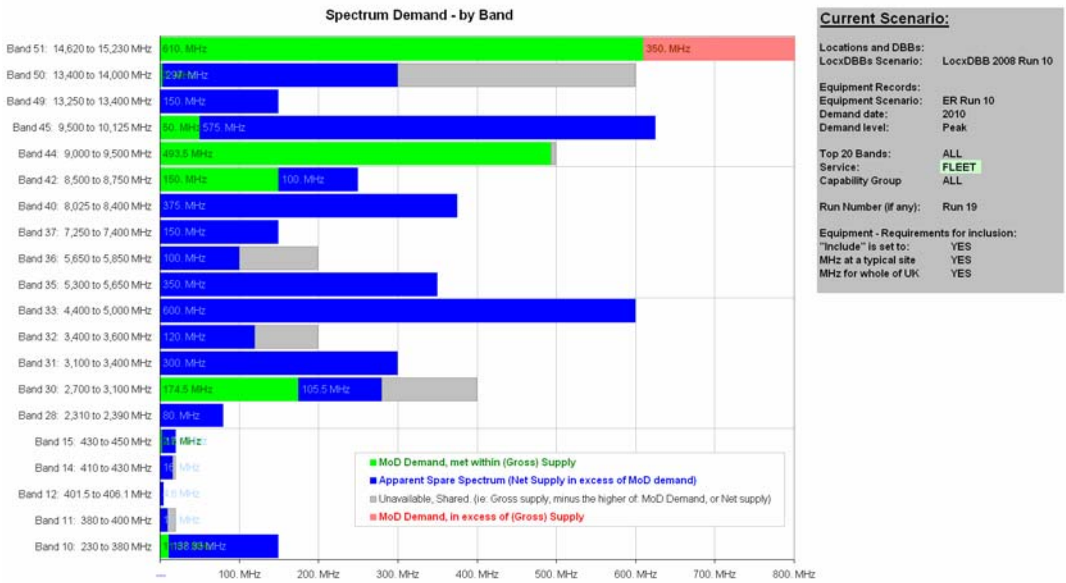


Figure 2-13: Demand for spectrum by band – FLEET – 2010

The picture for demand in 2015 is very similar; equipment changes have little impact on spectrum requirements. The small change in the 8500-8750MHz band is due to the T45 replacing the T42 destroyer.

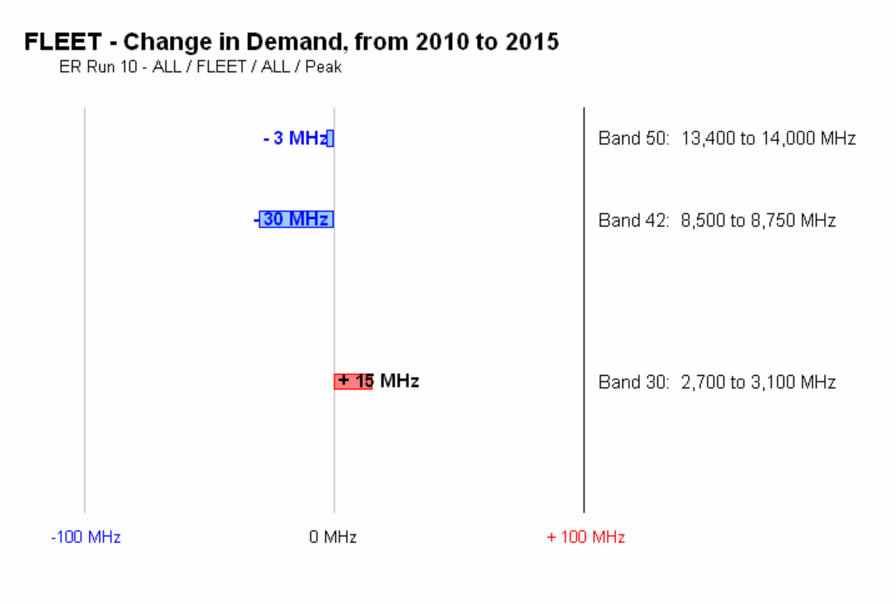


Figure 2-14: Demand for spectrum by band – FLEET – 2010

2.5.3 LAND

The graph below shows full use of the satellite bands around 8GHz and extensive use of bands at 230-380Mz and 4.4GHz, with some use in half the remaining bands. Total demand is comparable to FLEET.

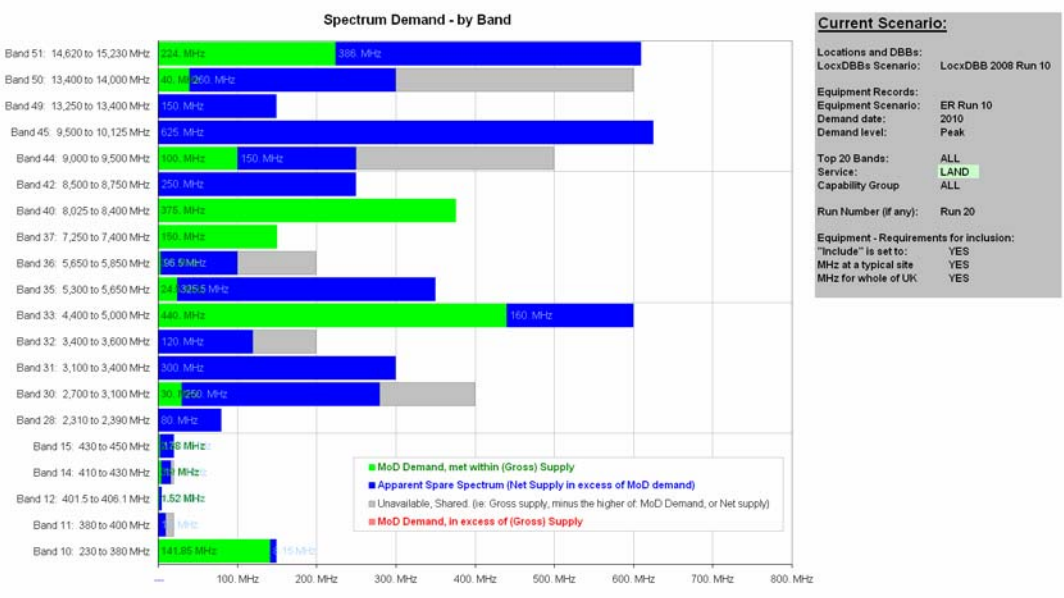


Figure 2-15: Demand for spectrum by band – LAND – 2010

For 2015, there are a few changes, e.g. an increase in demand in the band 230-380MHz (due primarily to the introduction of FIST), but the overall pattern is very similar to 2010. The drop in demand in 4400-5000MHz is due to Ptarmigan going out of service.

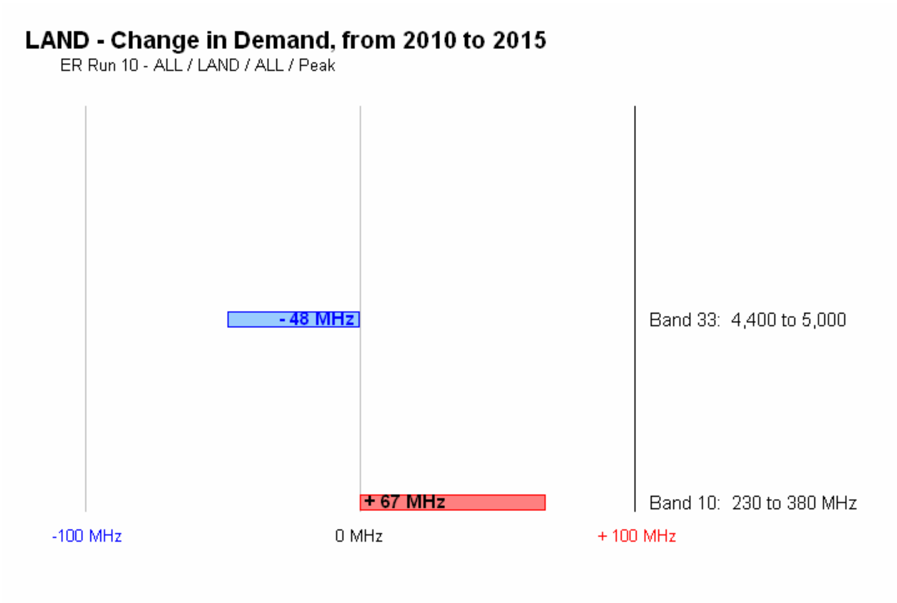


Figure 2-16: Demand for spectrum by band – LAND – 2015

2.5.4 OTHER

Demand not allocated to Air, Fleet or Land is relatively minor, appearing in only three bands.

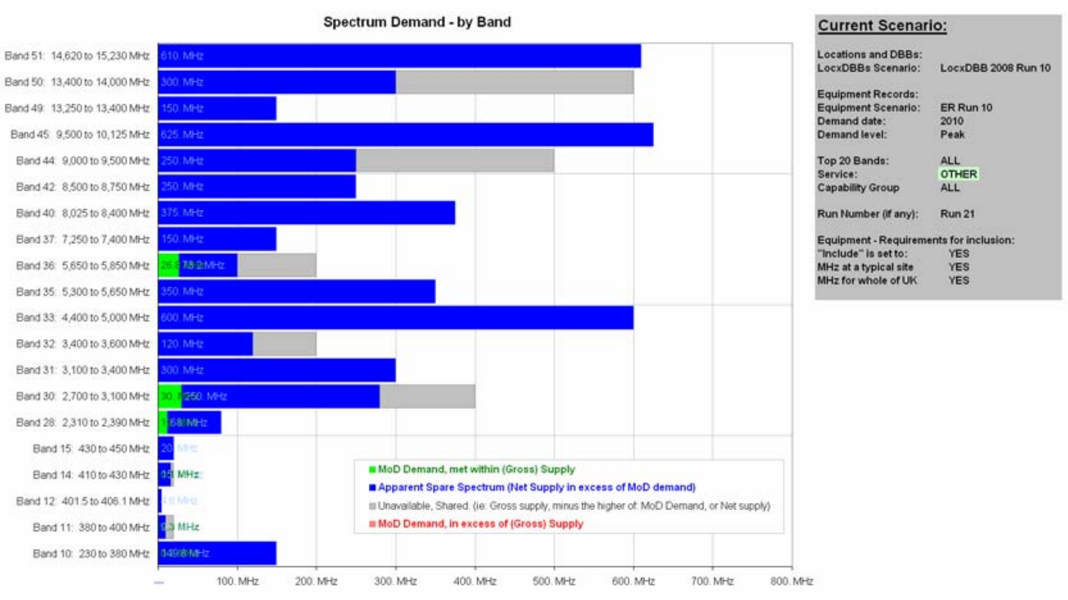


Figure 2-17: Demand for spectrum by band – OTHER – 2010

This picture does not change by 2015 (graph below intentionally blank, added for completeness only).

Figure 2-18: Demand for spectrum by band – OTHER – 2015

2.6 2010 - OVERALL SUPPLY AND DEMAND

2.6.1 Defence spectrum demand in the top 20 bands in 2010

In Section 2.3 above we have looked at supply and demand according to particular types of application. However, the total demand for spectrum will generally be met by allowing sharing across different applications. In practice MOD manages bands to allow sharing, and this significantly reduces the overall demand that we might expect by simply summing demand for the different applications.

In the sections below we aggregate the various demands, allowing for reuse between systems, to show the overall demand for spectrum by Defence in 2010. The demand in each band is discussed in detail in Section 3.

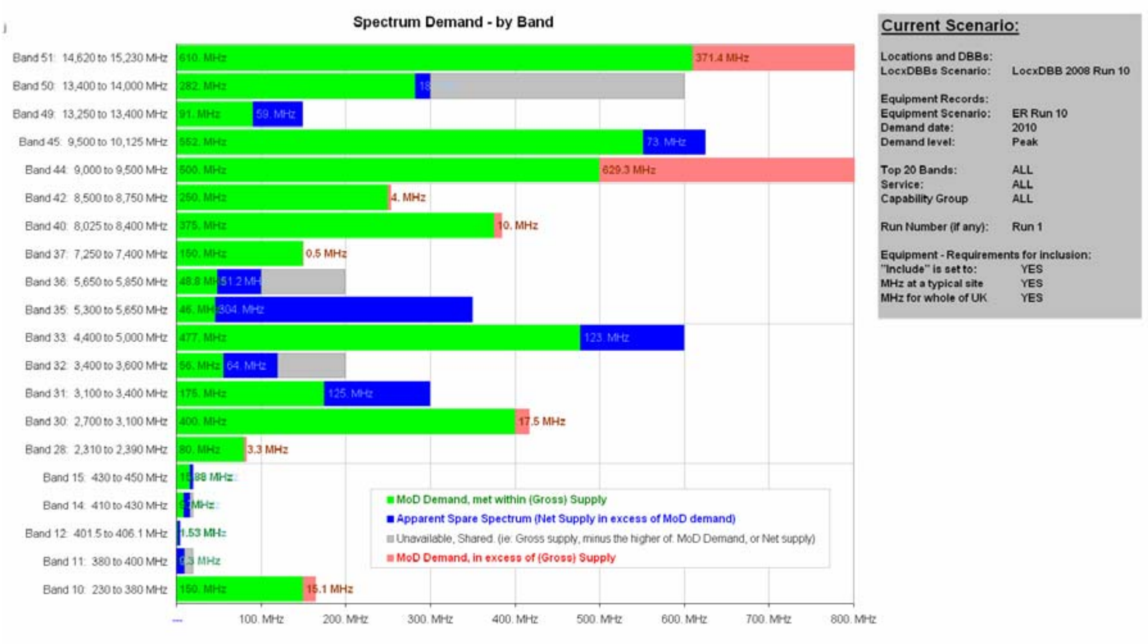


Figure 2-19: 2010 Defence spectrum demand by band

2.6.2 Where demand equals or exceeds supply

The main bands where demand appears to equal or exceed supply are as follows. Note that "excess" demand in this band may mean that usage – and, potentially, capability - is constrained, or it may mean that in practice MOD manage to avoid simultaneous peak demand from different users or systems – e.g. by careful scheduling, queuing, or limiting the power and range of systems for some users.

- 230-380MHz (voice and data links)
- 2310-2390MHz (video and data telemetry links)
- 2700-3100MHz (mixed use, mostly radar and weapons systems)
- 7250-7400MHz and 8025-8400MHz (predominantly satellite communications)
- 8500-8750MHz and 9000-9500MHz (weapons systems, wideband data links)
- 146250-15230MHz (radar and weapons systems).

2.6.3 Where supply exceeds demand

Bands with what appears to be "spare" spectrum are concentrated in the range 3-6 GHz:

- 3100-3400MHz[12]
- 3400-3600MHz
- 4400-5000MHz
- 5300-5650MHz
- 5650-5850MHz
- 9.5-10.1GHz and 13.2-13.4GHz.

It is important to emphasise here that these bands 'appear' to have spare spectrum. Our results for demand need to be considered together with the audit results to get a comprehensive picture.

2.7 OVERALL DEMAND BY LOCATION / REGION IN 2010

In Section 3 below, we consider geographic demand for spectrum in the different bands. The aggregation of this across all bands to show overall MOD usage is shown in Figure 2-20, this is of particular interest since civil demand tends to be in the urban areas.

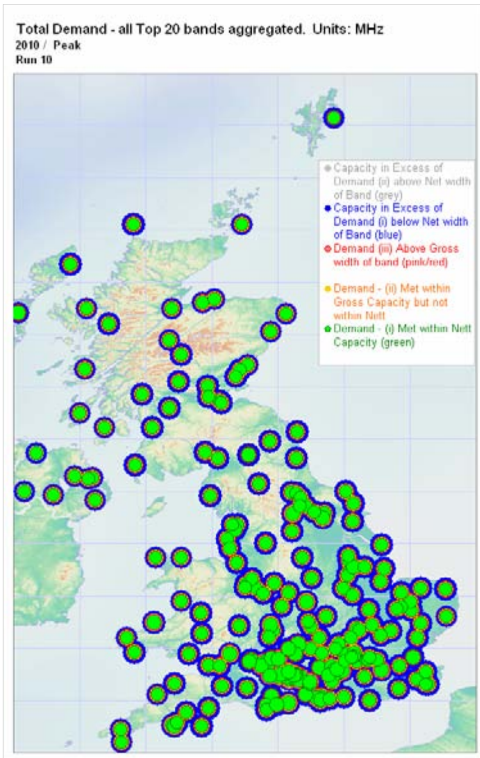


Figure 2-20: Total Defence spectrum demand by location

[12] Note that demand in this band changes significantly between 2008 and 2010, which leads us to a different conclusion (for 2010) to that found in the spectrum audit (which is based on 2008).

2.8 2008 – DIFFERENCES BETWEEN TODAY AND 2010

The chart below shows current usage. The main differences compared against 2010 are:

- The bands 230-380MHz and 4400-5000MHz are more congested in 2010 than currently, because 2010 sees the introduction of Falcon trunked radio systems, which will run in parallel with Ptarmigan for a period of time.
- The band 3100-3400MHz is less congested in 2010 than currently because the T93 ASACS radar (which has a high channel bandwidth) will be replaced by the T102 radar (with a narrower channel bandwidth) in the 2700-3100MHz band.

We also note that government is currently looking at the possibility of refarming the 2.7GHz – 3.4GHz band, moving radar allocations to free up some spectrum. Whilst this is unlikely to take effect by 2010, it could have an effect on that band before 2015.

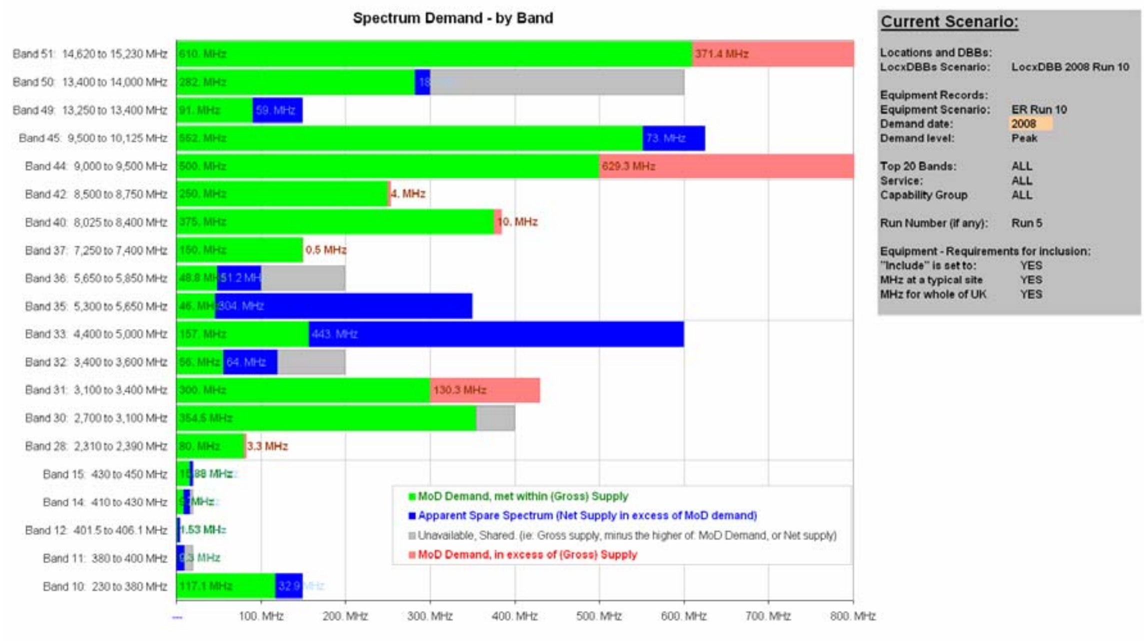


Figure 2-21: 2008 Defence spectrum demand by band

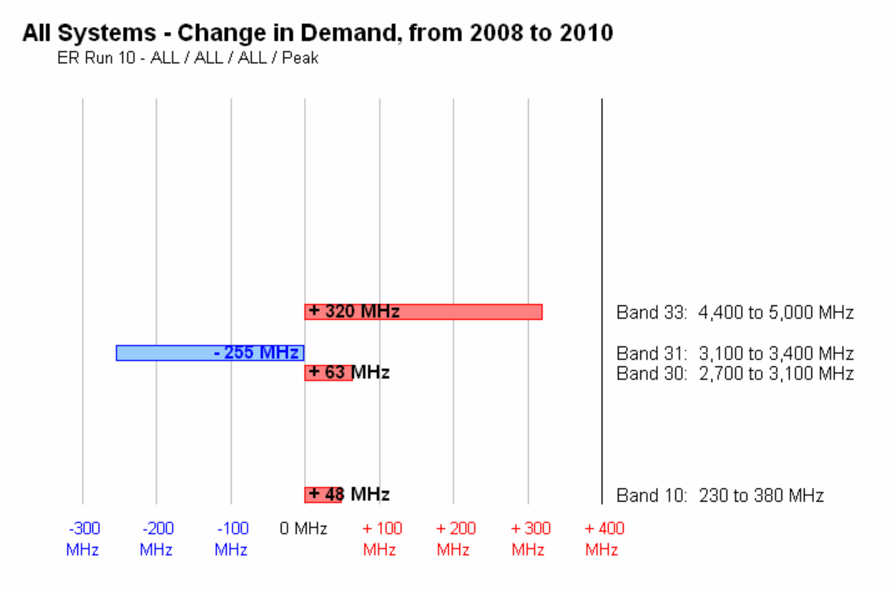


Figure 2-22: Change in spectrum demand from 2008 to 2010

2.9 2015 - OVERALL SUPPLY AND DEMAND

2.9.1 Defence spectrum demand in the top 20 bands in 2015

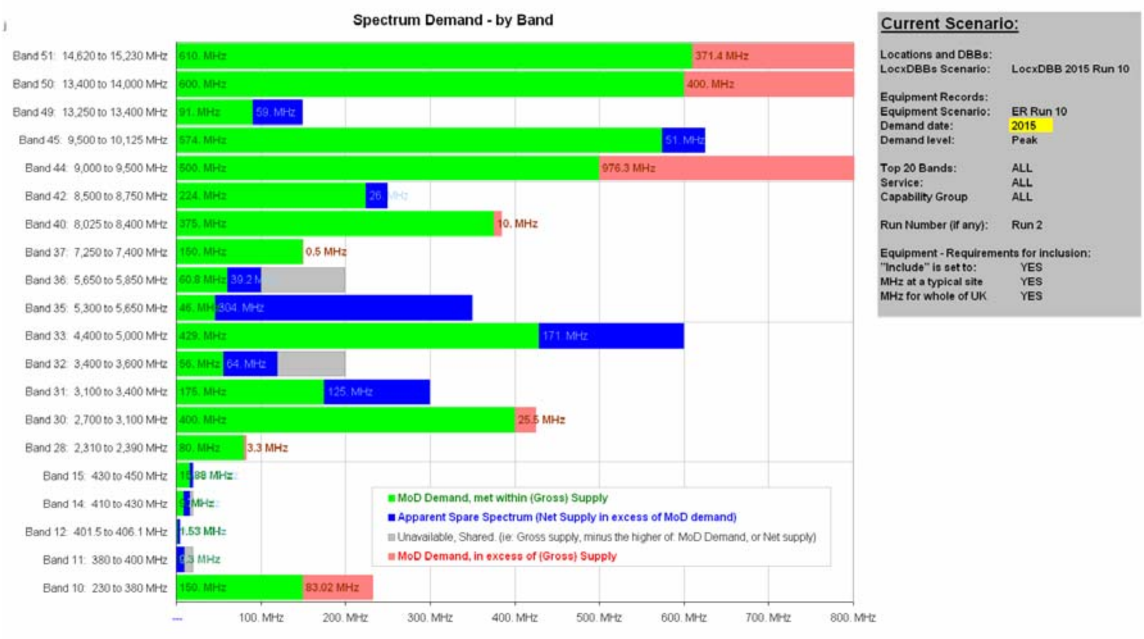


Figure 2-23: Demand by band - 2015

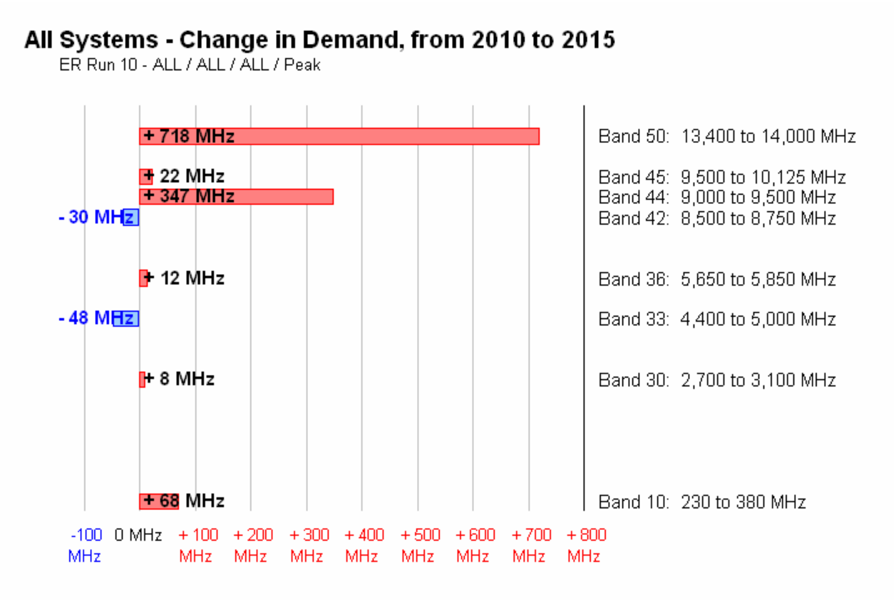


Figure 2-24: Changes in demand by band - 2010 to 2015

2.9.2 Where demand exceeds supply

The main bands where demand *appears to* exceed supply in 2015 are similar to 2010:

- 230-380MHz (voice and data links)
- 2310-2390MHz (video and data telemetry links)
- 2700-3100MHz (mixed use, mostly radar and weapons systems)
- 7250-7400MHz and 8025-8400MHz (predominantly satellite communications)
- 9000-9500MHz (weapons systems, wideband data links)
- At the upper end of the spectrum, for 2015,13400-14000MHz becomes congested, as well as 146250-15230MHz (Radar and weapons systems).

2.9.3 Where supply exceeds demand

As for 2010, bands with what appears to be “spare” spectrum are concentrated in the range 3-6 GHz:

- 3100-3400MHz, 3400-3600MHz, 4400-5000MHz, 5300-5650MHz, 5650-5850MHz
- 8.5-8.75GHz is now projecting a small surplus of supply over demand
- 9.5-10.1GHz and 13.25-13.4GHz.

2.10 FREQUENCY REUSE

In Section 2.4 above we have looked at supply and demand according to particular types of application. However, this demand for spectrum may be met either by allocating specific spectrum to each application, or by allowing sharing across different applications. In practice MOD manages bands to allow sharing, and this significantly reduces the overall demand.

In the sections above we aggregate the various demands to show the overall demand for spectrum by Defence in 2015. In several instances demand is seen to exceed supply. However in many cases Defence is able to manage this problem in a sensible way which is below the resolution of the data in our model. Typically such management techniques include:

- Confining certain radiation to remote or screened sites, making it possible for other systems to use the same spectrum across most of the UK
- Sector blocking on either a permanent (e.g. ASACS) or case by case basis (e.g. radars within a naval task group)
- Limiting the output power (e.g. on Bowman)
- Taking risk on acceptable levels of interference
- Temporal sharing.

2.11 OVERALL SUPPLY AND DEMAND (2027)

Our view of changes and drivers for change out to 2027 are discussed in Section 4. In summary, our main findings are:

- A great deal of the equipment which is in use or under development today will still be in service in 2027. Obsolescence is therefore unlikely to be a major cause of demand change.
- Similarly we do not see any major structural change in demand as a result of changed strategic imperatives. The shifts in defence posture arising as a result of increased emphasis on urban operations are already largely in place.
- There will be a number of technology improvements which could lead to improved spectral efficiency of radar systems. However, set against this we note that there is continuous demand for improved radar system performance, which will counteract improved efficiency to some extent.
- There will be increased demand for VHF and UHF communications links to support Network Enabled Capability and Situational Awareness to front line troops. Given the congestion in these bands today this needs careful attention.
- There is likely to be considerable additional demand for links to Unmanned Airborne Vehicles, to provide high speed data and surveillance link capability.

We therefore believe that the main significant changes will come about at a band-by-band level, as particular systems enter or leave service, or as opportunities for re-banding are addressed.

3. DEMAND BY FREQUENCY BAND (2010 / 2015)

3.1 INTRODUCTION

In each of the following sub-sections, the tables for each band show the total spectrum demand in that band, further split down by:

- MOD demand, met within (gross) supply
  - If MOD demand is greater than the size of the band, this entry is limited to the size of the band
- Apparent spare Spectrum (net supply in excess of MOD demand)
- Unavailable, shared (ie. gross supply, minus the higher of: MOD demand, or net supply)
  - This refers to bands where the MOD is already sharing spectrum with other users in the band. As a result of this sharing, the MOD is already receiving a discount on the AIP it would otherwise pay for the entire band
- MOD demand, in excess of (gross) supply.

Generally there may well be some small changes in spectrum demand for specific systems from 2010 to 2015 due to forecast changes in some locations and movements between locations, even if the system technical details do not change.

- For example, use of systems at new locations could increase or decrease overall spectrum demand as it will change the levels of interference suffered at other locations.

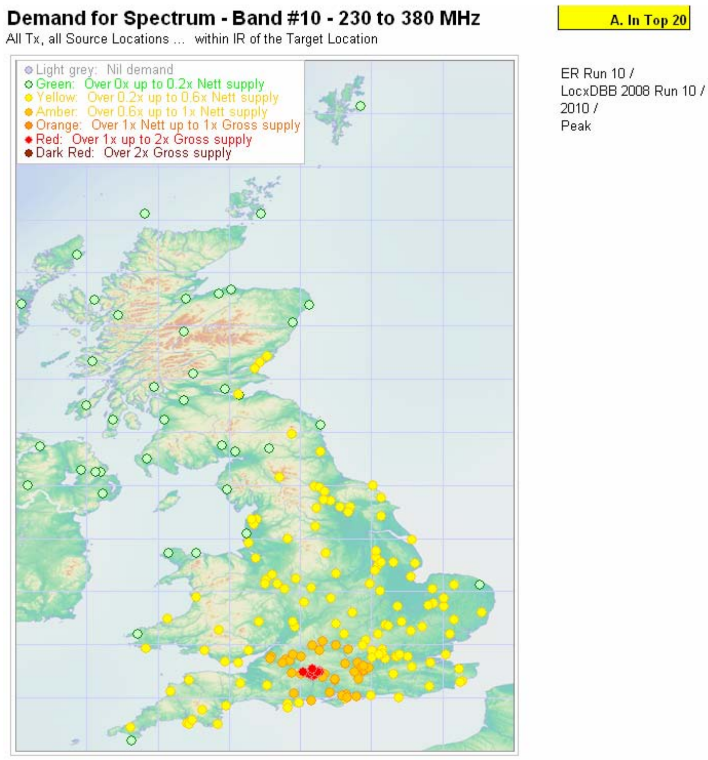
In addition, for each band we include:

- Maps showing how demand is distributed across the UK in 2010 and 2015
- Figures showing how demand is built up from applications
- Figures showing regional differences in demand in 2010
- Figures showing ‘usage’ of AIP cost, nationally and regionally

3.2 BAND 10 : 230MHZ – 380MHZ

3.2.1 2010 view

Band	Total Demand	MOD Demand, met within Supply	Apparent Spare Spectrum	Unavailable, Shared Spectrum	MOD Demand, in excess of Supply
230 to 380 MHz	165 MHz	150. MHz	---	---	15.1 MHz



Overall usage

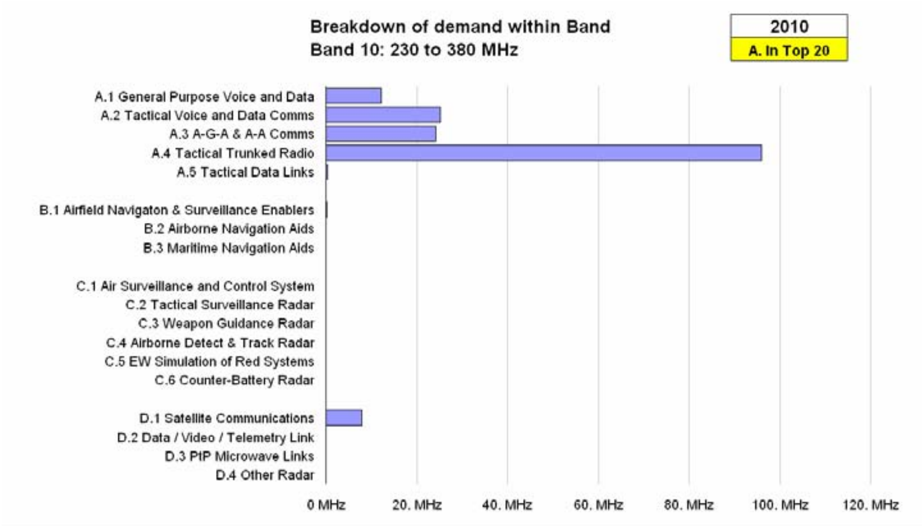


Figure 3-1: Demand for spectrum: 230-380MHz

This band shows a slight over-demand for spectrum of 15MHz. This is a very busy band, with lots of various voice comms (PMR, A/G/A, A/A, etc), trunked radio and tactical data radio. This is also the large NATO band and therefore relatively untouchable.

Key systems in use

There is significant spectrum demand in this band from:

- Ptarmigan & Cormorant trunked radio – these are currently in service
- FALCON trunked radio
  - FALCON is due to come into service in 2010
- HCDR accounts for 20MHz of demand in this band.

We model Ptarmigan / Cormorant and FALCON running in parallel in this band for 2010, with their demand for spectrum adding to each other (as opposed to one immediately replacing the other). While FALCON is replacing Ptarmigan and has an in-service date of 2010, Ptarmigan will be used for a further couple of years.

- There is potential to reduce spectrum demand during the Ptarmigan / FALCON transition if they can be treated as alternative systems demanding the same spectrum, rather than adding their separate demands as currently modelled.

Opportunistic uses of band

In practice, a number of different voice and narrow-band data systems and applications reside in this band. For the purposes of this study, we have generally amalgamated these into common groupings (e.g. PMR, A/G/A comms, etc, as indicated above) and included them in our modelling.

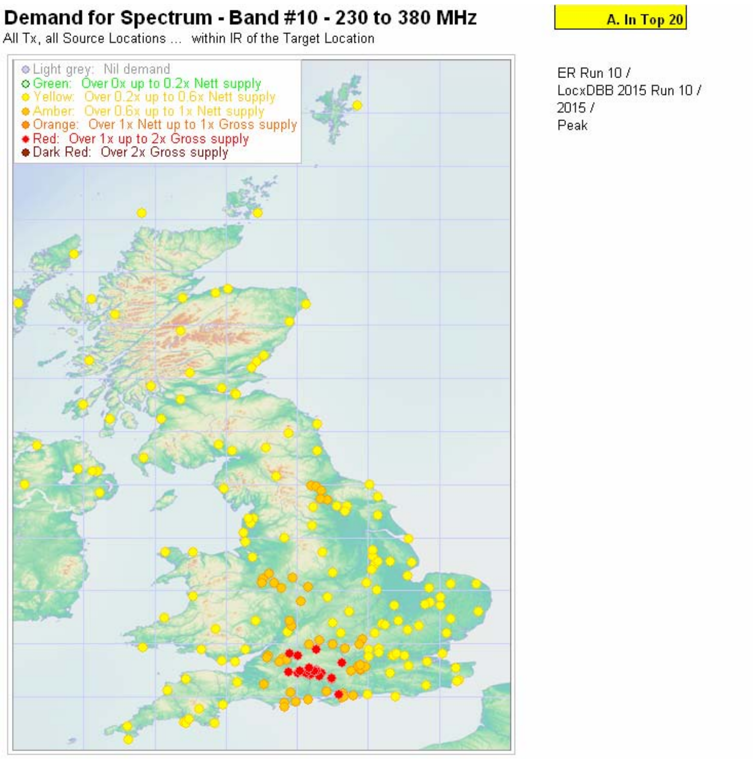
Other opportunistic users in the band, which have not been explicitly included in our modelling, include:

- Aerial target narrow-band data links (CATS)
- Some small special systems / usage
- Radio microphones for Customs & Excise.

In practice, these were not considered significant enough to affect overall demand.

3.2.2 2015 view

Band	Total Demand	MOD Demand, met within Supply	Apparent Spare Spectrum	Unavailable, Shared Spectrum	MOD Demand, in excess of Supply
230 to 380 MHz	233 MHz	150. MHz	---	---	83.0 MHz



The 2015 view sees a significant increase in demand for spectrum in this band (by nearly 68MHz). The main changes from 2010 are:

- While Ptarmigan will be out of service, there is continuing spectrum demand for Cormorant as well as FALCON. Therefore, there is a similar ongoing overall demand for training on tactical trunked radio.
- FIST is assumed to have come into service by 2015, requiring a number of broadband links in this band.
- Link 22 is also assumed to be in service by 2015, providing some additional spectrum demand.
- Due to forecast changes in some locations and movements between locations between 2010 and 2015, there is some small movement in overall spectrum demand for specific systems within this band, even if the system technical details do not change.
  - For example, use of systems at new locations could increase or decrease overall spectrum demand as it will change the levels of interference suffered at other locations.

3.2.3 Band analysis

Geographic issues and potential for geographic sharing

It can be seen from the maps for 2010 and 2015 above that the major hot spot for demand in this band is around Salisbury Plain.

For most of the rest of the UK, demand is for less than half the capacity of the band. There is a proportion of ubiquitous demand within this band (e.g. A-A comms, some A/G/A comms, some satellite comms) which will contribute to demand across the UK. There will also be training on Bowman HCDR and on some trunked radio systems in barracks and other smaller training areas across the UK. There is also some possibility of additional demand for Bowman HCDR operating on airborne platforms which could lead to wider geographic demand; this should not change the overall picture since 4x5MHz channels are already assumed to be used across the country.

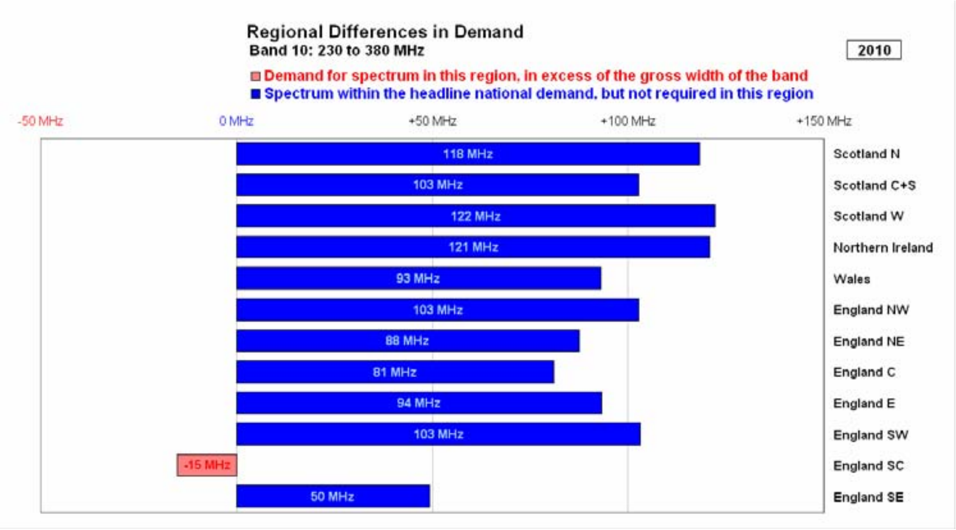


Figure 3-2: Differences in demand: 230-380MHz

Overall therefore, in theory there is the potential to share spectrum with other users across large areas of the UK. However, this is the harmonised NATO band and the practical and logistical problems in any sharing of spectrum in this band would be significant.

Overall therefore, in theory there is the potential to share spectrum with other users across large areas of the UK. However, this is the harmonised NATO band and the practical and logistical problems in any sharing of spectrum in this band would be significant.

Potential for spectrum release

In practice, there is very little prospect of national release of spectrum from within this band. This is a congested band, and the wide range of systems and users within it would make any release of spectrum on a national basis very difficult, requiring coordination of a large number of users.

Further, there is the fact that, as a NATO band, this would create further difficulties in releasing any spectrum in this band.

Other options for reducing spectrum requirement in this band

Some potential actions the MOD could take to free up spectrum in this band could include:

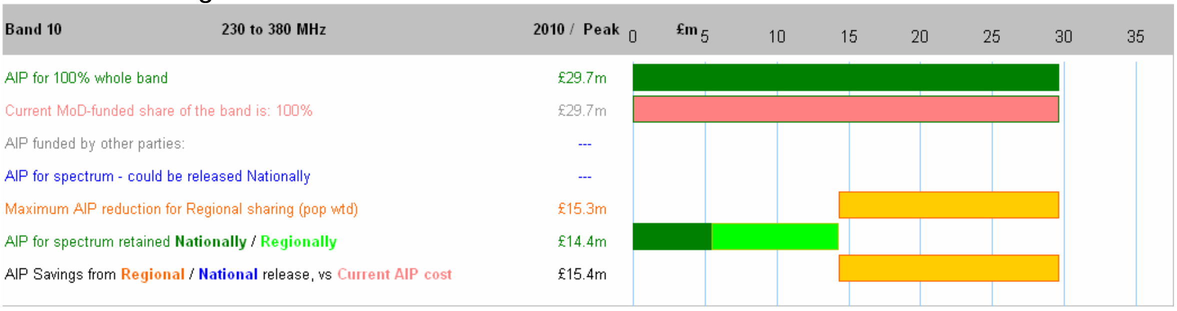
- Consolidating any use of site security comms, PMR comms, etc and replacing it by Airwave usage. However, MOD is likely to generate additional demand for spectrum in this and adjacent bands, which may still lead to little prospect for release.

In this band we believe that there is very little possibility for sharing on a temporal basis. Most of the systems residing in this band are either used operationally on a day-to-day basis, or regularly for training purposes.

Economic impact of demand

As discussed above, there is potential in this band for geographic sharing or release of spectrum. The graph below shows that regional sharing could account for just over half the AIP cost of this band, or £15M p.a., while retaining enough spectrum on a national and regional basis to deliver current required capability.

However, this is a very busy NATO band with a wide variety of users and systems scattered throughout the band.



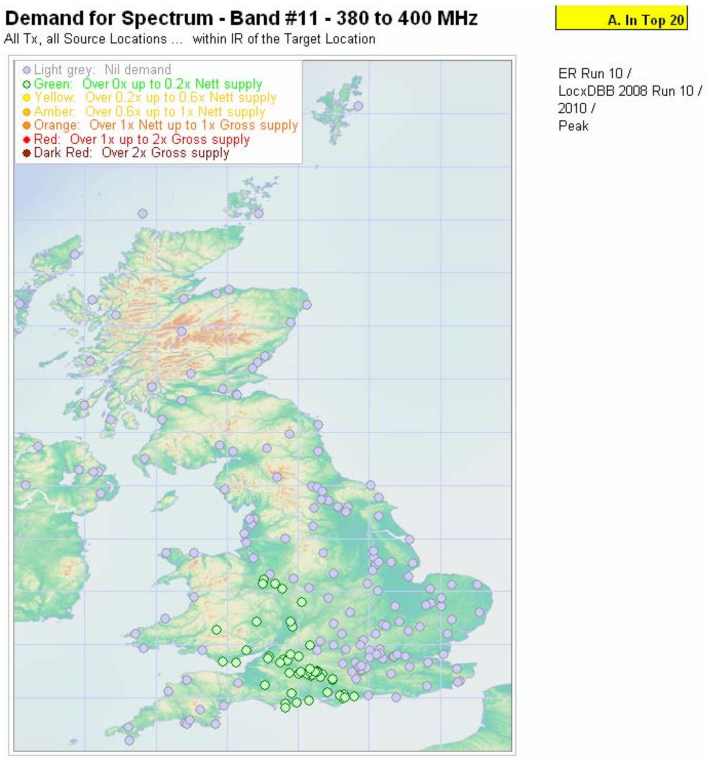
3.2.4 Notes on Cave audit findings

The Cave Audit report discusses the 230-400MHz band, which we split into two sub-bands. Otherwise, our findings for this band are largely in line with the Cave Audit findings, which state that "…major changes are unlikely in the short-to-medium term due to the nature of international planning and usage".

3.3 BAND 11 : 380MHZ – 400MHZ

3.3.1 2010 view

Band	Total Demand	MOD Demand, met within Supply	Apparent Spare Spectrum	Unavailable, Shared Spectrum	MOD Demand, in excess of Supply
380 to 400 MHz	0 MHz	0.3 MHz	9.7 MHz	10. MHz	---



Overall usage

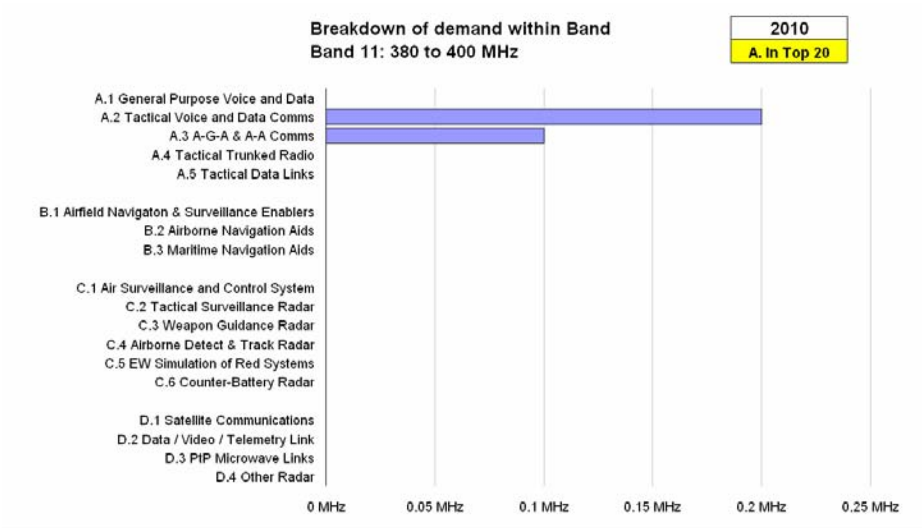


Figure 3-3: Demand for spectrum: 380-400MHz

This band shows a significant amount (approx 9.7MHz) of spare spectrum.

There are a lot of various voice comms (A/A, A/G/A, ship to shore, etc) in it, but none specific to this band. It is not clear that there is any application that specifically needs this band, so its use should only really be due to excess demand in other nearby bands, primarily 230MHz – 380MHz.

Key systems in use

No significant demand has been found specifically for this band.

- The only specific spectrum demand found in this band has been from some SF systems.

Overall, we believe that MOD could potentially move a lot of site security comms (PMR, SMRE) onto the Airwave network (assuming it can meet the necessary security levels and required capacity).

Opportunistic uses of band

Other opportunistic users in the band, which have not been explicitly included in our modelling for this band, include:

- A/A and A/G/A comms
- Ship/shore/ship comms
- Ship on-board comms
- Some sat comms
- Some ground transmission to UAVs.

Generally speaking, these systems and applications are all using 25kHz (or less) channels and, technically, could sit anywhere from 225MHz to 450MHz.

3.3.2 2015 view

Band	Total Demand	MOD Demand, met within Supply	Apparent Spare Spectrum	Unavailable, Shared Spectrum	MOD Demand, in excess of Supply
380 to 400 MHz	0 MHz	0.3 MHz	9.7 MHz	10. MHz	---

No significant changes in systems or spectrum demand are foreseen between 2010 and 2015.

3.3.3 Band analysis

Geographic issues and potential for geographic sharing

Based on the maps above, there is significant potential for sharing spectrum with non-MOD users on a geographic basis, as there is no single region creating a hot-spot of demand.

However, it should be noted that in practice, there are a number of different voice systems scattered around the country in this band, even if they do not explicitly need to be in this band specifically. Therefore, any release or sharing of spectrum would need careful coordination of a large number of users across the country.

Furthermore, this band is also a NATO essential band, so the same practical and logistical obstacles to releasing or sharing spectrum that apply to the 230 – 380MHz band also apply here.

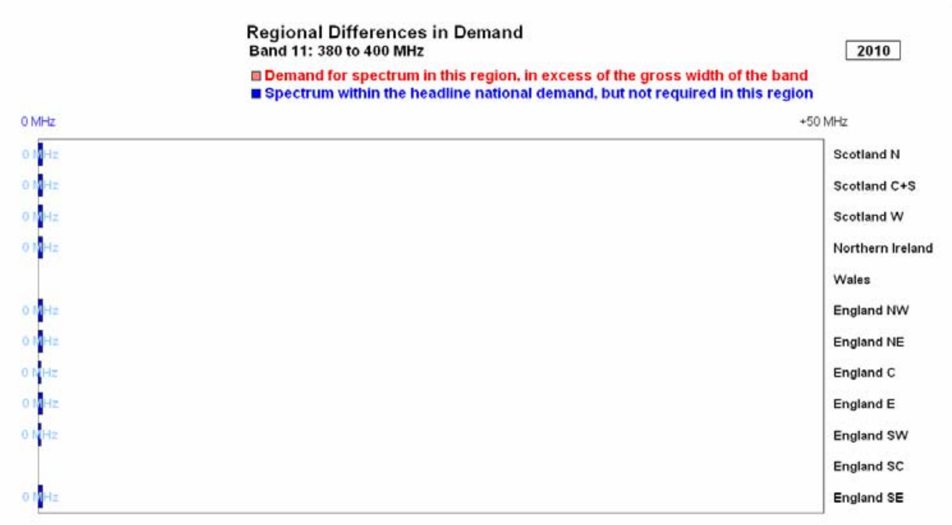


Figure 3-4: Differences in demand: 380-400MHz

Potential for spectrum release

As for geographic sharing, there appears to be reasonable grounds for looking at a national release of spectrum in this band. Again, in practice, this would require careful coordination due to the number of small voice comms systems residing in this band.

If such a release could be achieved, it is likely that an expansion of the paired spectrum available to the Airwave network could have significant commercial value. This could also have value to the MOD through replacing PMR / site security comms by Airwave usage.

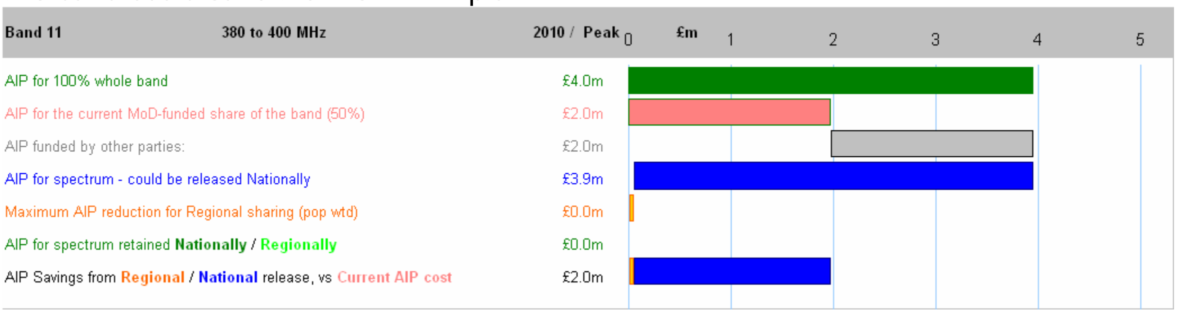
Other options for reducing spectrum requirement in this band

As mentioned above, there is no clear technical reason that any of the users residing in this band have to specifically remain here (rather than in the adjacent bands between 225MHz and 450MHz). Therefore, in principle, usage and subsequent spectrum demand could be moved into other bands, providing the capacity is there to accommodate it.

Economic impact of demand

There appears to be significant potential for national release of spectrum from within this band. While there are a number of users currently in this band, they are predominantly voice users and systems that could, in principle, be accommodated in other bands.

The MOD already shares this band with Airwave and so only pays 50% of the AIP cost for the whole band (£4M p.a. for the whole band). Re-organising and releasing spectrum in this band could save the MOD £2M p.a.



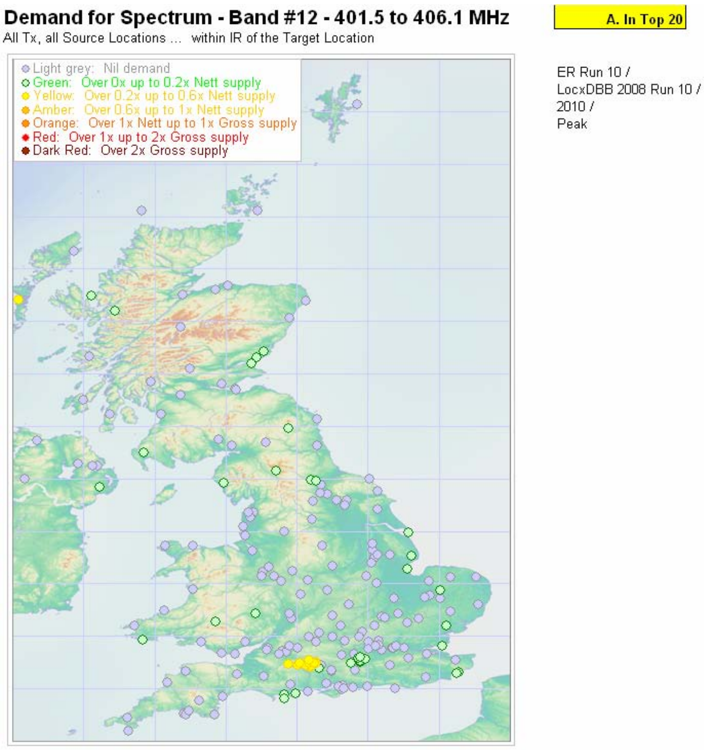
3.3.4 Notes on Cave audit findings

The Cave Audit report discusses the 230-400MHz band, which we split into two sub-bands. Otherwise, our findings for this band are largely in line with the Cave Audit findings, which state that "…the scope to admit other users into this band has been demonstrated. The MOD should consider the possibility of extending this at the margins of this band (e.g. further inroads in the 380-400MHz sub band)".

3.4 BAND 12 : 401.5MHZ – 406.1MHZ

3.4.1 2010 view

Band	Total Demand	MOD Demand, met within Supply	Apparent Spare Spectrum	Unavailable, Shared Spectrum	MOD Demand, in excess of Supply
401.5 to 406.1 MHz	2 MHz	1.53 MHz	3.08 MHz	---	---



Overall usage

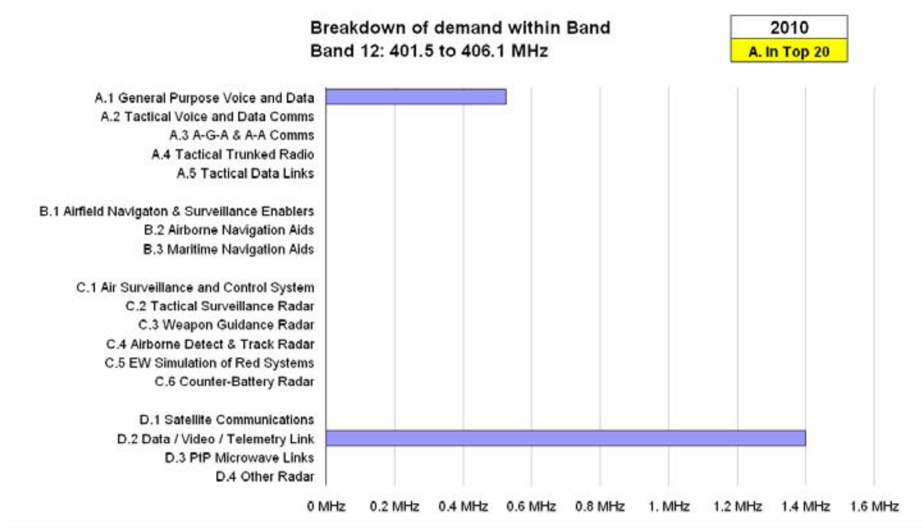


Figure 3-5: Demand for spectrum: 401.5-406.1MHz

This band shows a small amount of spare spectrum at 3.1MHz, although this is a significant proportion of the overall band.

Key systems in use

Significant spectrum demand in this band is from:

- Telemetry links for aerial targets (Banshee, Voodoo) and pop-up targets (e.g. at Larkhill)
- Radio Sonde transmissions
- Use of Low-level Urban Skills Trainer (LUST) on training areas (e.g. Salisbury Plain.

The above systems are scattered around relatively few locations and do not all interfere with each other. For example, the peak demand for use of LUST and pop-up target telemetry is at locations where aerial targets and radio sondes are not used. Therefore, the total demand figure above already allows for a level of geographical re-use of spectrum between different systems in this band.

Opportunistic uses of band

Other opportunistic users in the band, which have not been explicitly included in our modelling for this band, include:

- Some narrow-band data links to aerial targets
- EOD training
- Internal comms on submarines
- Some SF systems
- Some Met Office telemetry links.

Generally speaking, these systems and applications are all using 25kHz (or less) channels and, technically, could sit anywhere from 225MHz to 450MHz.

3.4.2 2015 view

Band	Total Demand	MOD Demand, met within Supply	Apparent Spare Spectrum	Unavailable, Shared Spectrum	MOD Demand, in excess of Supply
401.5 to 406.1 MHz	2 MHz	1.53 MHz	3.08 MHz	---	---

No significant changes in systems or spectrum demand are foreseen between 2010 and 2015.

3.4.3 Band analysis

Geographic issues and potential for geographic sharing

There should be significant potential for geographic sharing of spectrum in this band. From the map above, it can be seen that nationally worst-case demand is for less than half the band, but these are at a few scattered locations (e.g. Salisbury Plain). There are large regions where the spectrum demand within the band is significantly less than this.

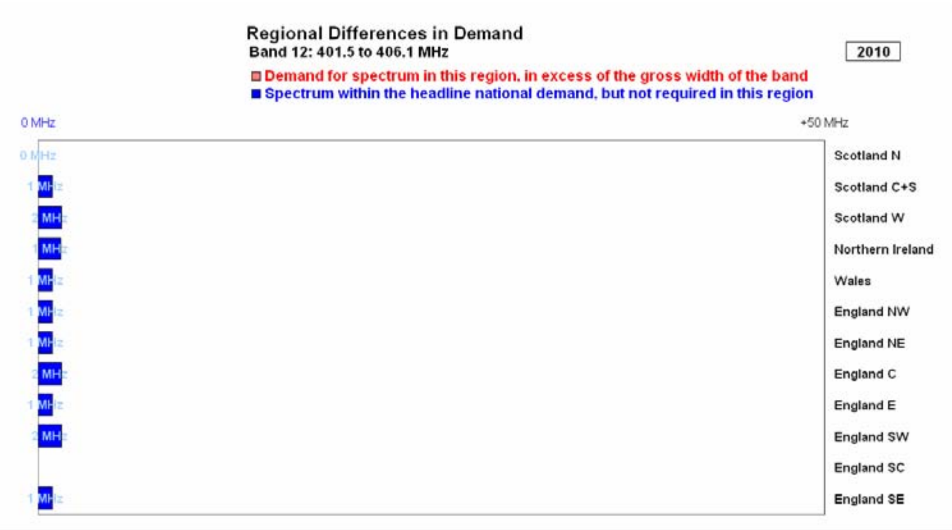


Figure 3-6: Differences in demand: 401.5-406.1MHz

Potential for spectrum release

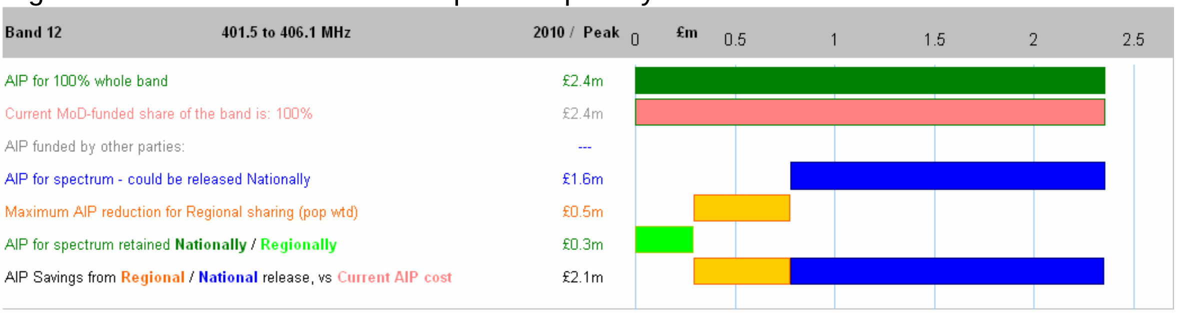
Again, there should be significant potential for releasing spectrum from within this band. The major users in this band are at specific locations and not very widespread.

Other options for reducing spectrum requirement in this band

As noted above, the total demand figure for this band already allows for a level of geographical re-use of spectrum between different systems in this band at different locations. Therefore, any further reduction of spectrum demand in this band would probably have to be though moving use into other bands.

Economic impact of demand

There appears to be significant potential for national release of spectrum within this band, with further opportunities for additional regional releases. The MOD is responsible for 100% of this band, but could save up to £2M p.a., while retaining enough spectrum on a regional basis to deliver current required capability.



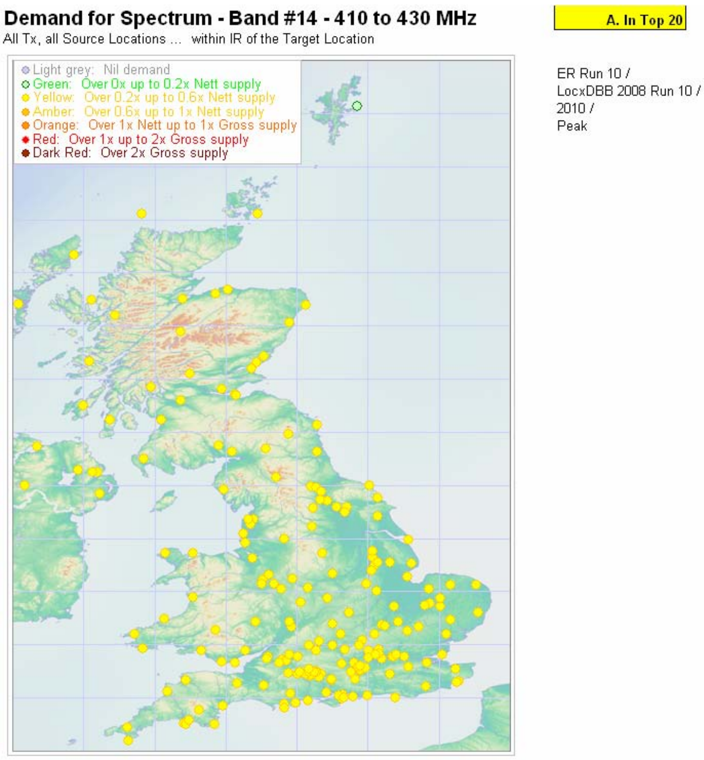
3.4.4 Notes on Cave audit findings

The major difference between our findings and those of the Cave Audit for this band are to highlight the potential for geographic sharing in this band due to the localised nature of the hot-spots of demand in this band.

3.5 BAND 14 : 410MHZ – 430MHZ

3.5.1 2010 view

Band	Total Demand	MOD Demand, met within Supply	Apparent Spare Spectrum	Unavailable, Shared Spectrum	MOD Demand, in excess of Supply
410 to 430 MHz	9 MHz	9. MHz	7. MHz	4. MHz	---



Overall usage

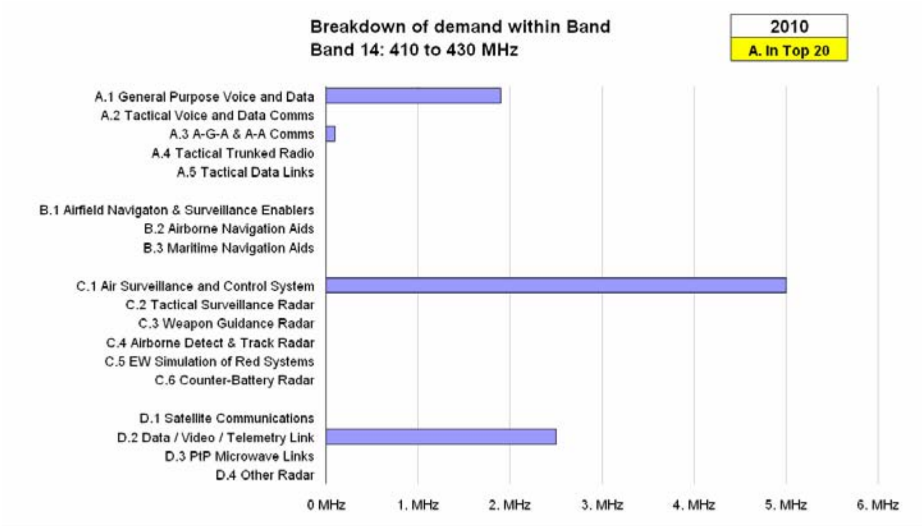


Figure 3-7: Demand for spectrum: 410-430MHz

This band shows a small amount of spare spectrum at 7MHz, although this is a significant proportion of the overall band.

Key systems in use

There is specific demand in this band for:

- BMEWS at Fylingdales (split with Band 15 below)
- Telemetry links for aerial targets (Banshee, Voodoo) and pop-up targets (e.g. at Larkhill)
- Use of Low-level Urban Skills Trainer (LUST) on training areas (e.g. Salisbury Plain
- Some small amounts of special application spectrum demand.

Otherwise, there is also some PMR demand in this band.

Opportunistic uses of band

Other opportunistic users in the band, which have not been explicitly included in our modelling for this band, include:

- CVF deckcomms
- EOD system datalink
- Some aerial target narrowband data links
- Some mobile voice comms
- Some specific flight terminating systems at Aberporth.

Generally speaking, these systems and applications are all using 25kHz (or less) channels and, technically, could sit anywhere from 225MHz to 450MHz.

3.5.2 2015 view

Band	Total Demand	MOD Demand, met within Supply	Apparent Spare Spectrum	Unavailable, Shared Spectrum	MOD Demand, in excess of Supply
410 to 430 MHz	9 MHz	9. MHz	7. MHz	4. MHz	---

No significant changes in systems or spectrum demand are foreseen between 2010 and 2015.

3.5.3 Band analysis

Geographic issues and potential for geographic sharing

In practice in this band, there is a hot-spot of demand around Salisbury Plain, boosted by the use of LUST on the training area there. Otherwise, there is demand for less than half the band in the rest of the country, raising the possibility of geographic sharing or release of spectrum.

Note that spectrum demand at Fylingdales is treated as omni-directional for modelling purposes Note that the primary issue here is protecting reception at Fylingdales – usage in this band is currently assessed by MOD.

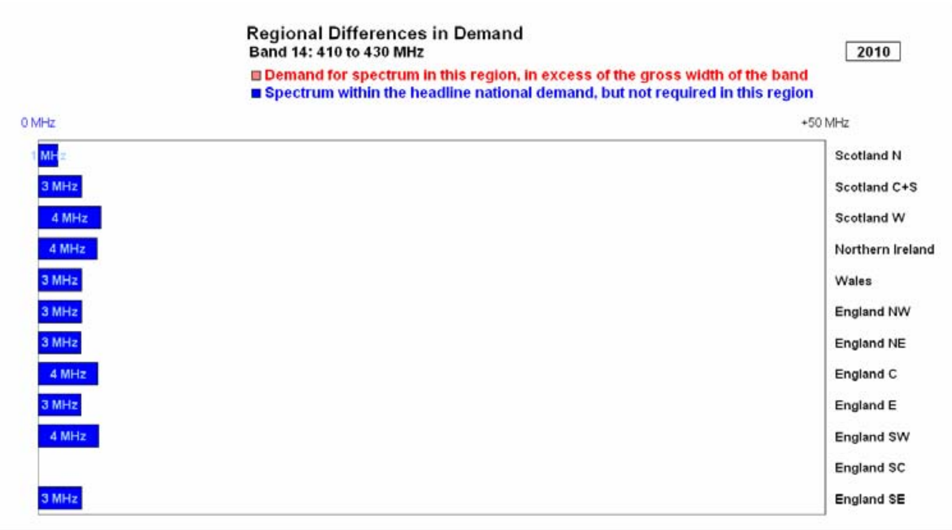


Figure 3-8: Differences in demand: 410-430MHz

Potential for spectrum release

The potential for a national release of spectrum is reduced by the peak of demand around Salisbury Plain. However, even so, there is nearly half of the band that is apparently spare and could be released on a national basis.

Other options for reducing spectrum requirement in this band

As discussed previously, the use of PMR in this band does not appear to be strictly necessary and could be migrated to other bands or even on to the Airwave network if appropriate.

Furthermore, the BMEWS at Fylingdales operates across this band and the next band up (Band 15). It may be that this does not strictly need to operate in this band, but this would need careful coordination with the operation at Fylingdales.

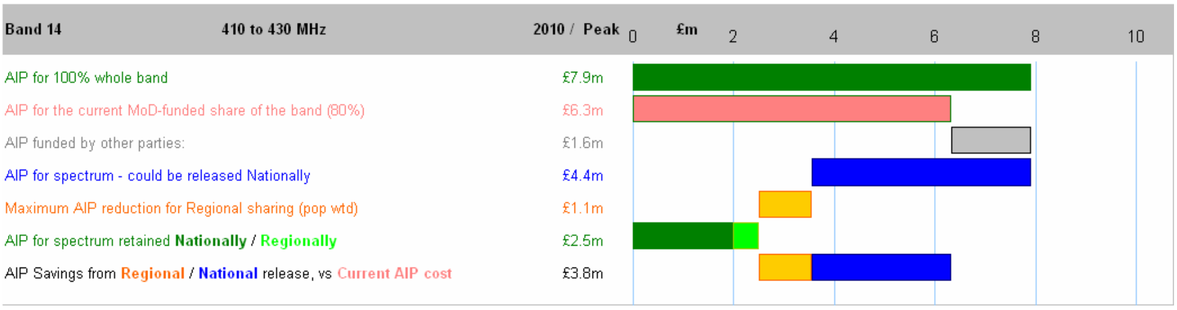
Also, as reception and transmission at Fylingdales is treated as omni-directional, it is effectively adding to the spectrum demand at Salisbury Plain. If, in fact, BMEWS transmission is directional and does not interfere at Salisbury Plain, this could further reduce overall spectrum demand in this band.

Economic impact of demand

The MOD currently pays only 80% of the AIP cost for the whole band. However, there is significant potential for national release of spectrum in this band, as well as some potential for further regional sharing.

This could realise savings of nearly £4M p.a., while retaining enough spectrum on a national and regional basis to deliver current required capability.

As discussed above, if transmission at Fylingdales can be confirmed as directional, this would increase the potential for both national and regional sharing, creating further potential savings.



3.5.4 Notes on Cave audit findings

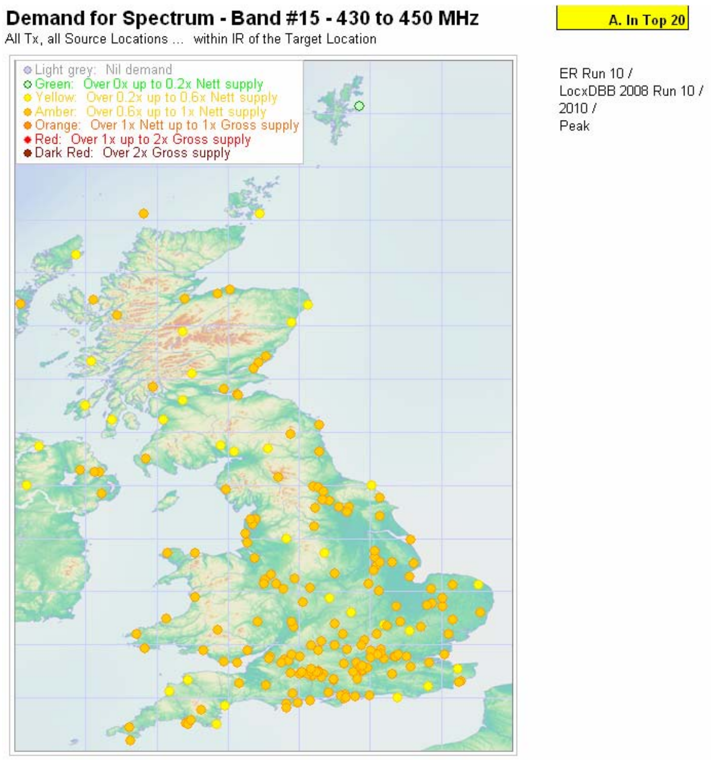
Our findings for this band are largely in line with the Cave Audit findings, which state that “There appears to be good potential for further release of spectrum in this band below 420MHz”.

We further highlight the potential for geographic sharing in this band due to the localised nature of the hot-spots of demand in this band, particularly around Salisbury Plain.

3.6 BAND 15 : 430MHZ – 450MHZ

3.6.1 2010 view

Band	Total Demand	MOD Demand, met within Supply	Apparent Spare Spectrum	Unavailable, Shared Spectrum	MOD Demand, in excess of Supply
430 to 450 MHz	16 MHz	15.88 MHz	4.13 MHz	---	---



Overall usage

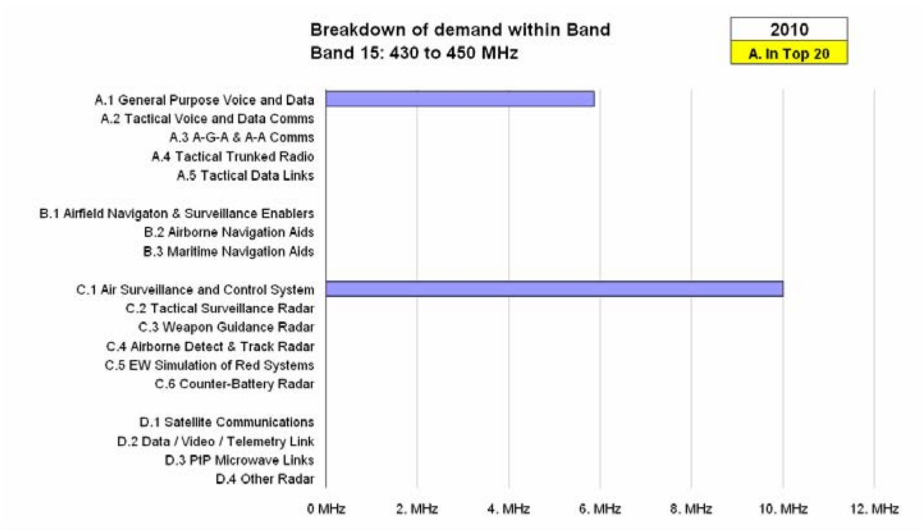


Figure 3-9: Demand for spectrum: 430-450MHz

This band shows a small amount of spare spectrum at 4MHz.

Key systems in use

There is specific demand in this band for:

- BMEWS at Fylingdales (split with Band 14 above)
- Use of Low-level Urban Skills Trainer (LUST) on training areas (e.g. Salisbury Plain.

Otherwise, there is some PMR and Intrinsically Safe Areas comms (effectively PMR with specialised terminals).

Opportunistic uses of band

Other opportunistic users in the band, which have not been explicitly included in our modelling for this band, include:

- Some A/G/A comms
- Some narrowband data links for aerial targets
- Some EOD comms
- Some ship-to-ship comms.

As for the previous bands between 225MHz to 430MHz, generally speaking, these systems and applications are all using 25kHz (or less) channels and, technically, could sit anywhere from 225MHz to 450MHz.

3.6.2 2015 view

Band	Total Demand	MOD Demand, met within Supply	Apparent Spare Spectrum	Unavailable, Shared Spectrum	MOD Demand, in excess of Supply
430 to 450 MHz	16 MHz	15.88 MHz	4.13 MHz	---	---

No significant changes in systems or spectrum demand are foreseen between 2010 and 2015.

3.6.3 Band analysis

Geographic issues and potential for geographic sharing

The peak demand for this band is shown as around Salisbury Plain in the map above. Also, this band shows significant demand for this band throughout the UK, reducing the options for geographic sharing of spectrum.

However, a large proportion of this UK-wide demand is due to treating reception and transmission from Fylingdales as omni-directional. If the level of directionality of this can be confirmed, this would significantly reduce the spectrum demand in this band for large areas of the UK.

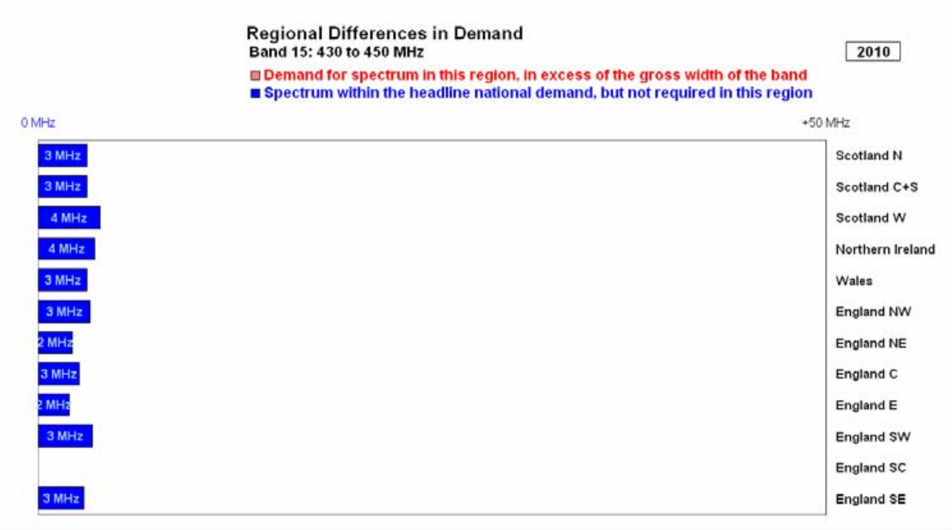


Figure 3-10: Differences in demand: 430-450MHz

Potential for spectrum release

Furthermore, if the transmission at Fylingdales is confirmed as directional, it potentially does not add to the hot-spot of demand at Salisbury Plain, reducing the peak total demand for spectrum in this band. This would improve the options for a national release of spectrum in this band.

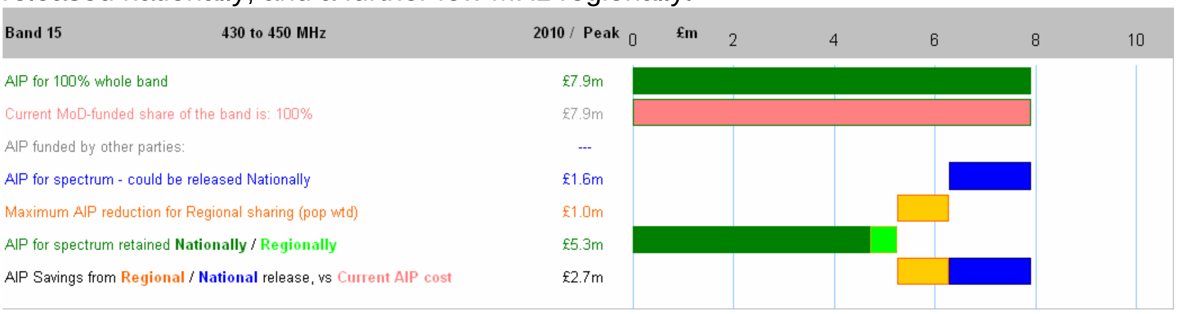
Finally, as discussed in previous sections, there is a widespread use of PMR comms in this band. If this could be cleared out and moved into another band, for example on to the Airwave network, this would further improve the options for national release of spectrum.

Other options for reducing spectrum requirement in this band

None identified.

Economic impact of demand

There appears to be some potential for national release of spectrum within this band, with some further opportunities for additional regional releases. MOD is responsible for 100% of this band, but could save £2.6M p.a., while retaining enough spectrum on a national and regional basis to deliver current required capability. Approximately 4MHz could be released nationally, and a further few MHz regionally.



3.6.4 Notes on Cave audit findings

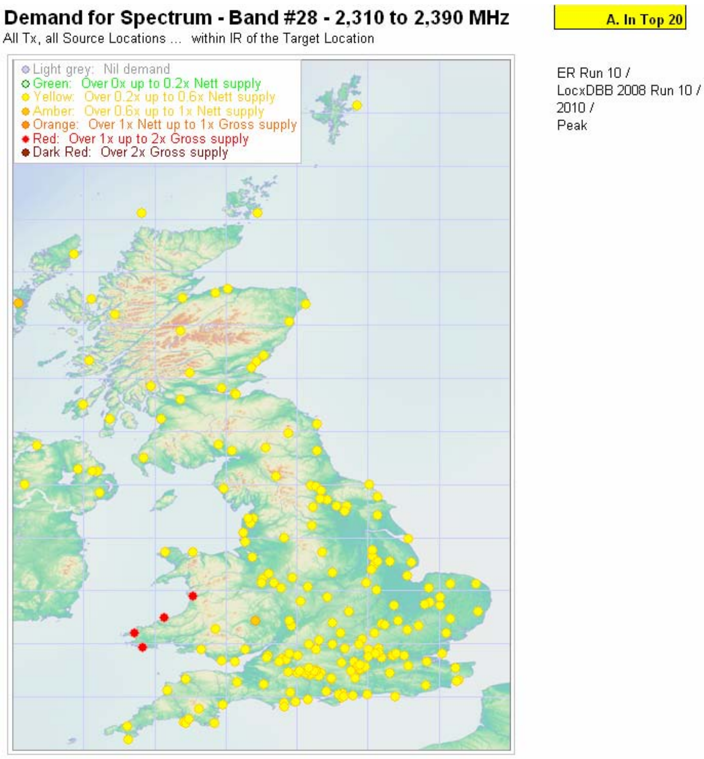
Overall, the findings of this report are in line with the Cave Audit findings. We can see a small potential for release or sharing of spectrum in this band, but it is limited by:

- Protection of Reception at Fylingdales
- Transmission from Fylingdales
- The scattered nature of PMR and other voice applications throughout the band.

3.7 BAND 28 : 2310MHZ – 2390MHZ

3.7.1 2010 view

Band	Total Demand	MOD Demand, met within Supply	Apparent Spare Spectrum	Unavailable, Shared Spectrum	MOD Demand, in excess of Supply
2,310 to 2,390 MHz	83 MHz	80. MHz	---	---	3.3 MHz



Overall usage

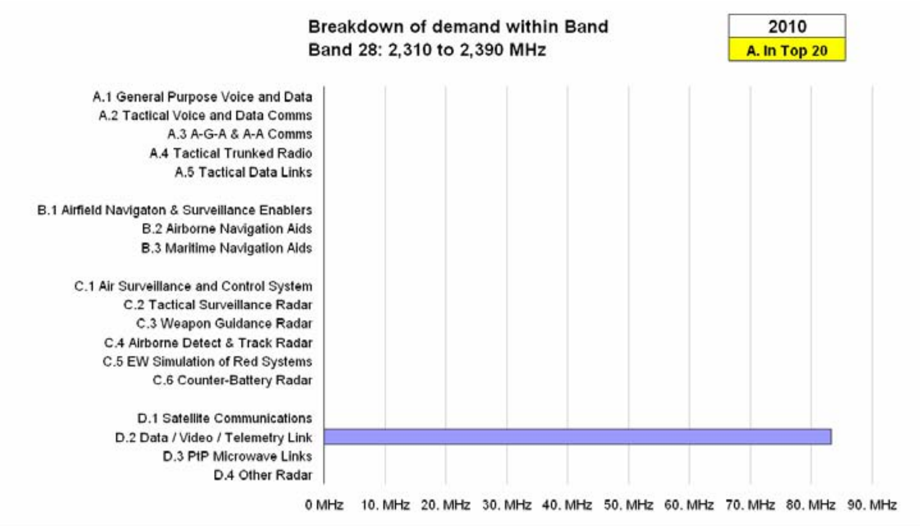


Figure 3-11: Demand for spectrum: 2310-2390MHz

This band shows a slight over-demand for spectrum.

Key systems in use

There is significant spectrum demand in this band from:

- Ubiquitous demand for ISTAR-type video downlinks
- UAV telemetry at Aberporth – HALE/Reaper and Watchkeeper
  - These have separate, additive demand, but there may be potential to re-use and co-ordinate use of the same frequencies.
- Hawk trainer link
- Ubiquitous demand for RAIDS – Rangeless Airborne Instrumentation & Debriefing System (on Harriers)
- Missile telemetry at Hebrides ranges – Brimstone and AMRAAM
  - Again, these have separate, additive demand, but there may be potential to re-use and co-ordinate use of the same frequencies.

Aberporth and Hebrides do not interfere with each other, with the largest demand at Aberporth.

- We recommend a detailed localised study of likely peak loading and propagation at Aberporth and Hebrides to determine accurate demand and the ability to share this band on a geographical basis with these relatively remote sites.

Opportunistic uses of band

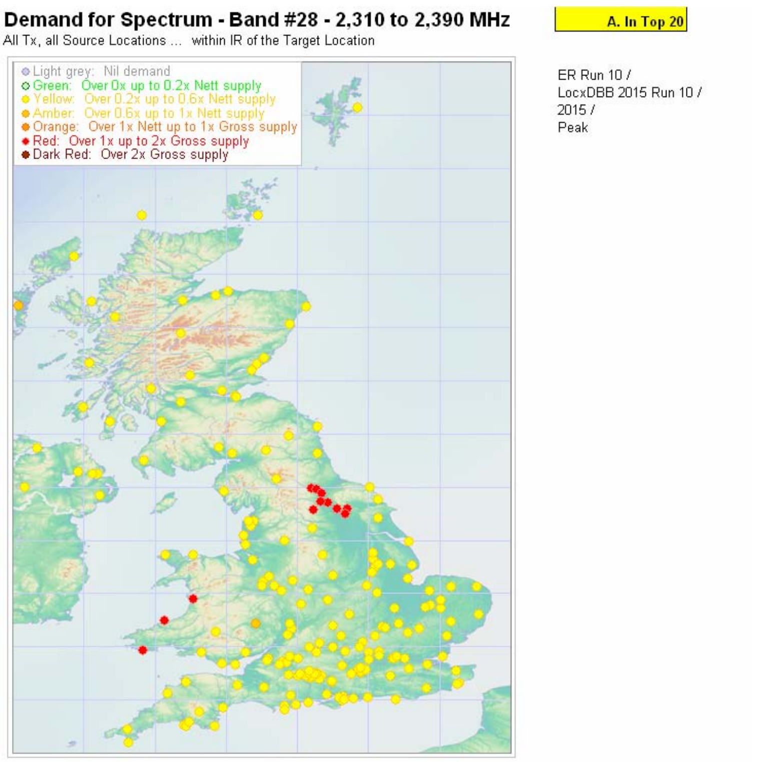
Other opportunistic users in the band, which have not been explicitly included in our modelling for this band, include:

- Telemetry links for ejection seat testing
- Flight safety monitoring.

It is felt that these systems are so localised that they are not likely to add to the overall spectrum demand in this band.

3.7.2 2015 view

Band	Total Demand	MOD Demand, met within Supply	Apparent Spare Spectrum	Unavailable, Shared Spectrum	MOD Demand, in excess of Supply
2,310 to 2,390 MHz	83 MHz	80. MHz	---	---	3.3 MHz



No significant changes in systems or spectrum demand are foreseen between 2010 and 2015.

- Note that although the total demand numbers do not change, the map of usage does actually change from 2010 to 2015, as shown above. This reflects the expectation that UAVs will fly out of a second site by 2015.

3.7.3 Band analysis

Geographic issues and potential for geographic sharing

There is some ubiquitous demand in this band from the airborne ISTAR links and RAIDS system.

Other than these, it can be seen from the maps above that in 2010, the hotspot of demand is around Aberporth and the UAV test and development work there, with a secondary hot-spot around the Benbecula range. In 2015, it is likely that the use of UAVs will be more widespread in the UK, potentially reducing the options for geographic sharing of spectrum.

Overall, therefore, there appears to be significant potential for a geographic release or sharing of spectrum in this band. Peaks of MOD demand are centred around a few specific locations.

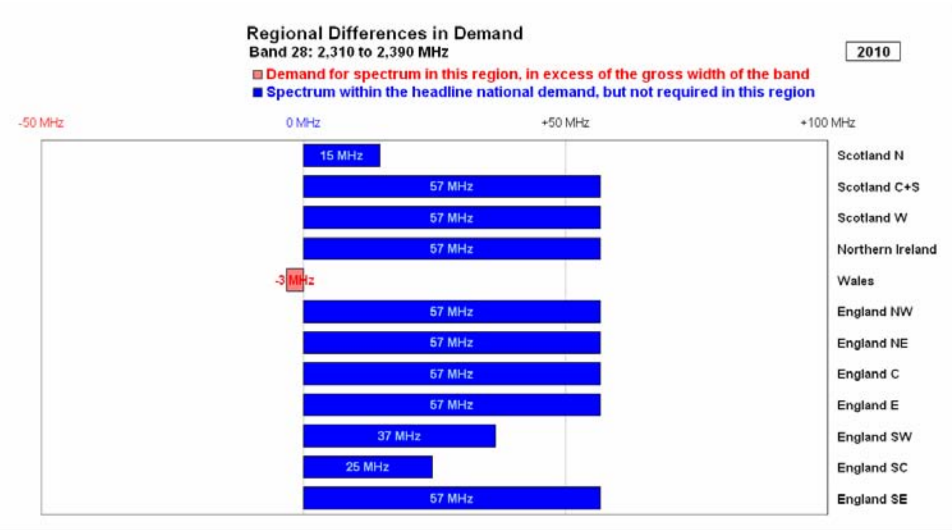


Figure 3-12: Differences in demand: 2310-2390MHz

Potential for spectrum release

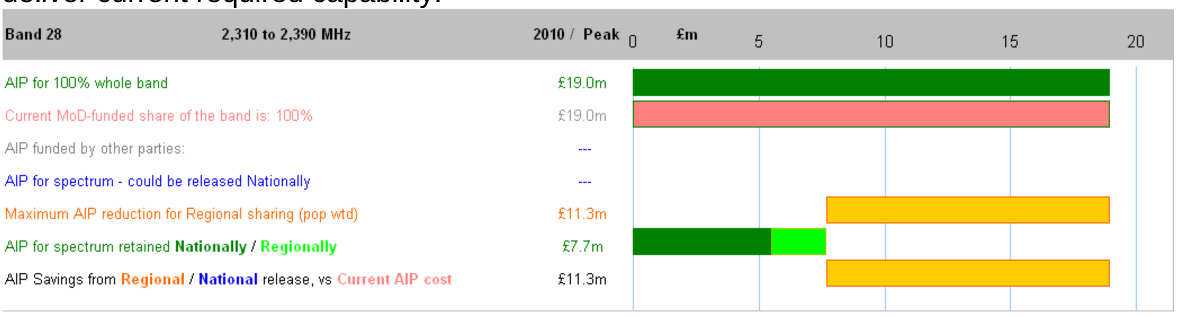
There appears to be little option for a national release of spectrum in this band. There is significant use of wideband data and telemetry links, particularly at a small number of specific locations (e.g. Aberporth, Hebrides ranges), as well as some ubiquitous airborne spectrum demand.

Other options for reducing spectrum requirement in this band

There may be further options for reducing spectrum requirements in this band. The peak demands at Aberporth and Benbecula are due to multiple channels for UAV testing and missile testing respectively. It is entirely possible that these systems and applications could/should share the same channel(s) on a temporal basis. This would have the potential to reduce the overall demand at these locations and therefore for the whole band.

Economic impact of demand

There appears to be some potential for regional release of spectrum within this band, but not on a national basis. The MOD is responsible for 100% of this band, but could save just over £11M p.a., while retaining enough spectrum on a national and regional basis to deliver current required capability.



3.7.4 Notes on Cave audit findings

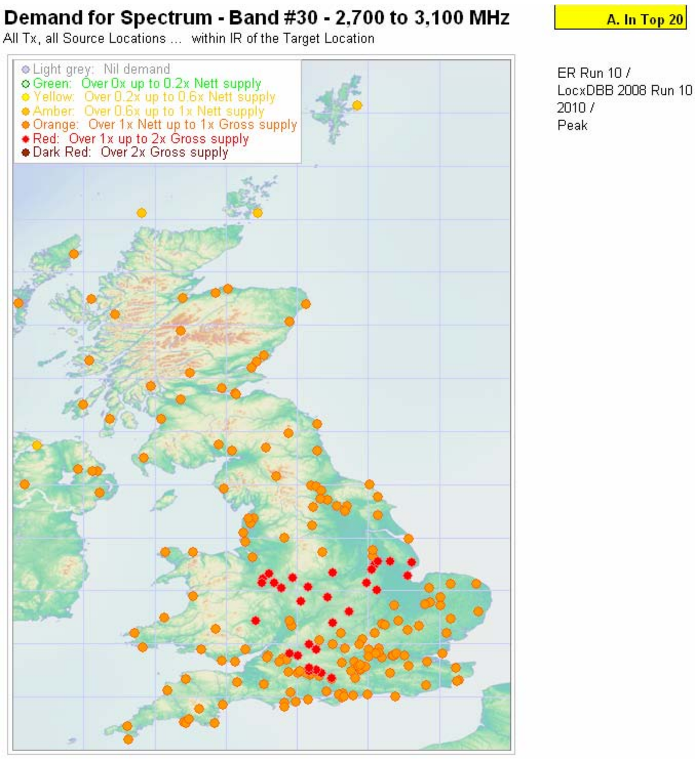
The findings in this report differ from the Cave Audit findings in that we highlight above the potential for geographic sharing or release of spectrum due to the localised nature of some of the demand within this band.

At a national level, our findings are largely in line with the Cave Audit findings, highlighting the difficulty of releasing spectrum at a national level in this band, but with the potential to rationalise some usage.

3.8 BAND 30 : 2700MHZ – 3100MHZ

3.8.1 2010 view

Band	Total Demand	MOD Demand, met within Supply	Apparent Spare Spectrum	Unavailable, Shared Spectrum	MOD Demand, in excess of Supply
2,700 to 3,100 MHz	418 MHz	400. MHz	---	---	17.5 MHz



Overall usage

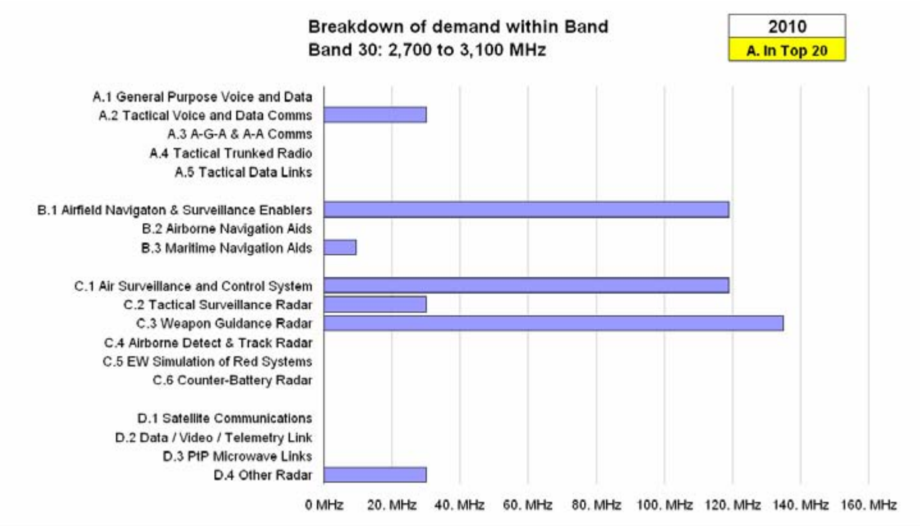


Figure 3-13: Demand for spectrum: 2700-3100MHz

This band shows a slight over-demand for spectrum.

Key systems in use

There is significant spectrum demand in this band from:

- Ubiquitous and localised demand from a range of naval radars – T996, T1008, SAMPSON, LRR, T968.
- Some details for these radars were not available at the date of this report, with the potential for subsequent impact on the results for this band. However, as this band already appears over-subscribed, it seems unlikely that changes in the technical parameters for some systems will change that overall picture.
- ASACS demand from the T101 radar and T102 radar (to be introduced in 2009, replacing the T93 radar).
  - Although these radars use two channels at a time, we allow for a larger number of channels per site to allow for spare channels if needed (as these are operational systems).
- Watchman primary surveillance radars on airfields
- Some range safety radars at artillery ranges
- Some other special systems sitting between 2.5GHz and 3.5GHz, that we currently model as falling within this band.
  - These may well be able to sit in other bands and/or co-exist with other systems in-band, thus reducing overall spectrum demand for this band.

Opportunistic uses of band

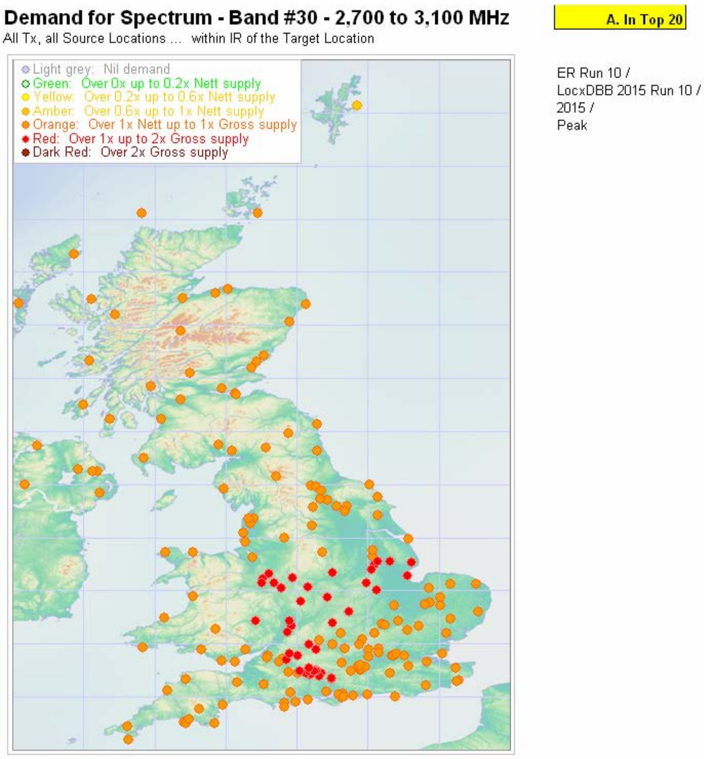
Other opportunistic users in the band, which have not been explicitly included in our modelling for this band, include:

- Potential EW training at Spadeadam
- Trial marine radars
- Met Office wind radars.

It is felt that these systems are either so localised that they are not likely to add to the overall spectrum demand in this band, or do not represent MOD demand for spectrum.

3.8.2 2015 view

Band	Total Demand	MOD Demand, met within Supply	Apparent Spare Spectrum	Unavailable, Shared Spectrum	MOD Demand, in excess of Supply
2,700 to 3,100 MHz	426 MHz	400. MHz	---	---	25.5 MHz



As can be seen from the map above, there are no significant changes in demand from 2010 (the image above is virtually identical to the 2010 demand map). The 2015 view sees a slight increase in demand for spectrum in this band (by only 8MHz). The main change from 2010 is:

- A change in the use of naval radars, primarily due to the T42 destroyers being replaced by T45 destroyers. This sees increases in the use of SAMPSON and LRR radars, and a decrease in the use of T996 radars.
  - This is the major cause of change in this band by 2015, increasing the overall spectrum demand for naval radars, much of which is treated as ubiquitous demand (i.e. it can occur anywhere).
  - Some details for these radars were not available at the date of this report, with the potential for subsequent impact on the results for this band. This could change the overall picture for 2015.

3.8.3 Band analysis

Geographic issues and potential for geographic sharing

From the maps above, it would appear that there is little opportunity for geographic release or sharing of spectrum in this band. The level of either ubiquitous demand (from naval radars at sea) or near-ubiquitous demand (from ASACS sites) is large enough that there are few areas where there is a lot of apparently spare spectrum.

It is also worth noting that the MOD already shares in this band with the CAA for airfield radars such as Watchman.

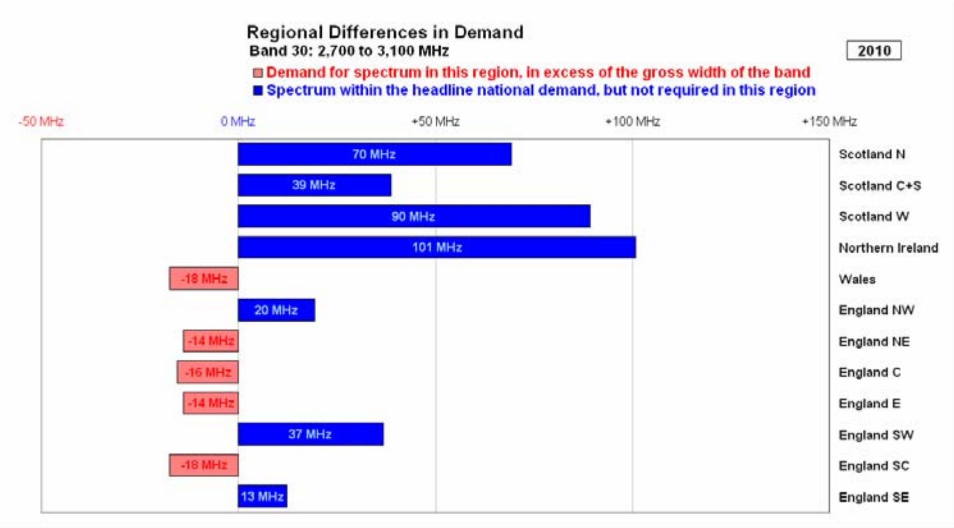


Figure 3-14: Differences in demand: 2700-3100MHz

Potential for spectrum release

Again, as noted above, there is little initial prospect of releasing spectrum on a national basis in this band. There is significant demand for ASACS radars, a range of naval radars and Watchman radars.

One option may be to look at potentially spare spectrum in the band (3100MHz – 3400MHz) and consider migrating usage into that band, should this band be considered more commercially interesting. However, given the use of CAA and Met Office radars in this band, this is not a decision the MOD could take in isolation in order to free up spectrum in this band.

Other options for reducing spectrum requirement in this band

Naval radars at sea are treated as ubiquitous for this study, which therefore add to the interference suffered at all locations, including those inland.

- This may be appropriate in some cases, since at this operating frequency, many of these radars have operating ranges measured in hundreds of kilometres. However, in practice, some locations may not in practice suffer interference from these systems.

We currently assume that surveillance and weapons radars need to be deconflicted using different channels. If, in practice, this deconfliction can be achieved using pulse profiling (or other techniques) to differentiate radar transmissions in the same channel, this will reduce the number of channels needed and therefore reduce the total spectrum demand in this band.

ASACS radars account for 120MHz of demand in the band. However, in practice, they may not contribute directly to overall demand within the band due their directionality (effectively, they will point out to sea and not interfere significantly inland).

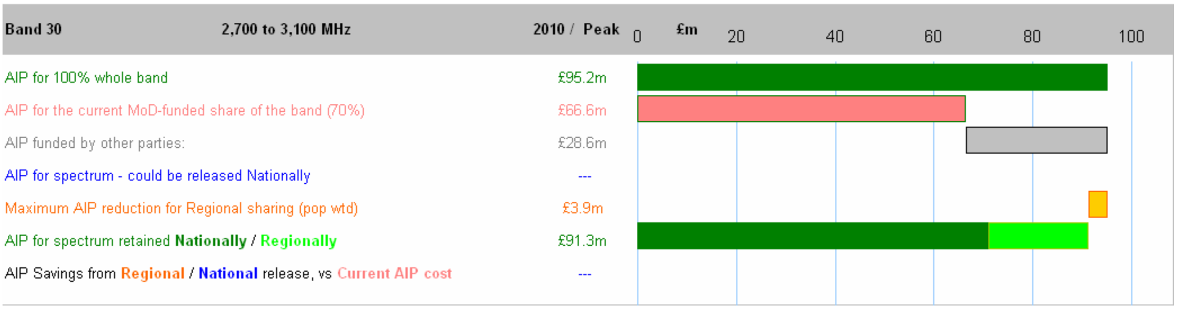
- There is therefore the potential for reducing demand further by carrying out a more detailed study of the potential co-existence of ASACS radars with other land-based systems within this band.

- We note that Ofcom is about to undertake a review of radar usage of this band.

Economic impact of demand

The MOD pays 70% of the AIP for this whole band (£95M p.a.), due to existing sharing arrangements with other parties, such as the CAA.

There appears to be some small potential for sharing on a regional basis, but while this could account for nearly £4Mp.a., the existing MOD demand appears to be for more than 70% of the band anyway. Therefore, it is not clear that any such saving could actually be realised.



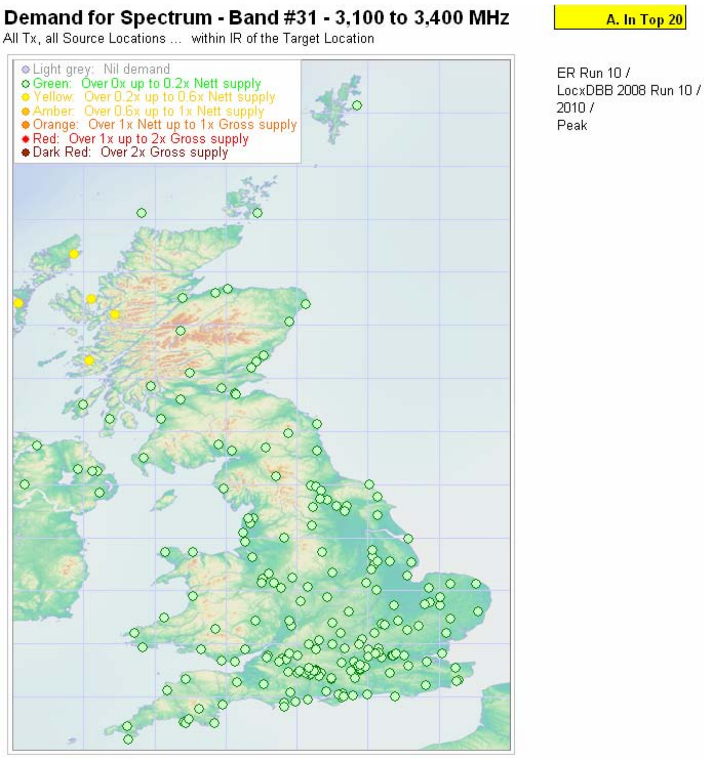
3.8.4 Notes on Cave audit findings

The Cave Audit reports on 2700-3400MHz as a single band, while this report splits this into two sub-bands. Taking this into account, the findings of this report are consistent with the Cave Audit findings, as we see little immediate prospect of releasing spectrum in this band without technological advances in MOD radars to increase frequency sharing between systems.

3.9 BAND 31 : 3100MHZ – 3400MHZ

3.9.1 2010 view

Band	Total Demand	MOD Demand, met within Supply	Apparent Spare Spectrum	Unavailable, Shared Spectrum	MOD Demand, in excess of Supply
3,100 to 3,400 MHz	175 MHz	175. MHz	125. MHz	---	---



Overall usage

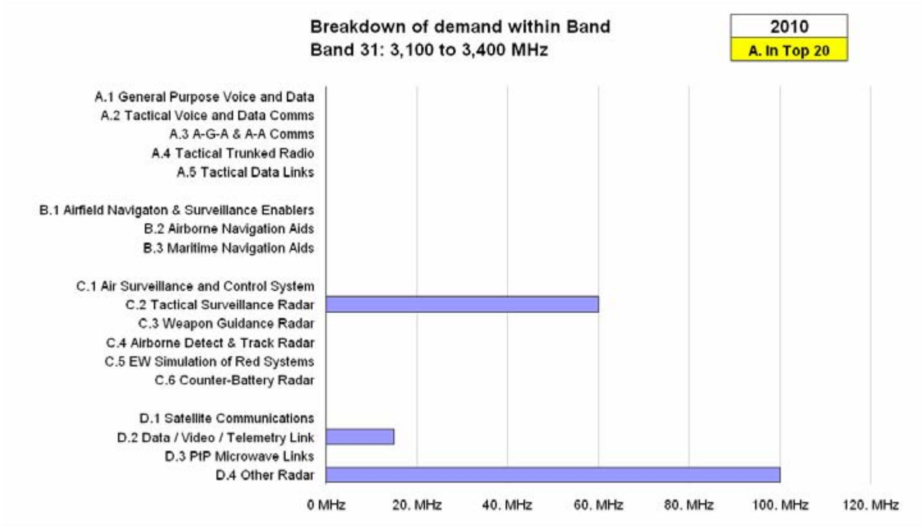


Figure 3-15: Demand for spectrum: 3100-3400MHz

This band shows a significant amount of spare spectrum at 125MHz.

Key systems in use

There is significant spectrum demand from:

- Ubiquitous demand from AWAC (E3-A/D) multi-mode radar
- Mirach and Banshee aerial target radars and telemetry links (at Benbecula)
  - We recommend a detailed localised study of likely peak loading and propagation at Benbecula to determine accurate demand and the ability to share this band on a geographical basis with this remote site.

It is worth noting that T93 ASACS radars currently sit in this band and use a significant amount of spectrum (~250MHz) due to a very wide channel bandwidth, but are due to be replaced by T102 radars (which will operate in the 2700MHz – 3100MHz band) in 2009.

Additionally, SAMPSON LRR radars are included in the 2700-3100MHz band, but may also operate and create demand here.

Opportunistic uses of band

Other opportunistic users in the band, which have not been explicitly included in our modelling for this band, include:

- Radar development at Cowes
- EW calibration.

It is felt that these systems are either so localised that they are not likely to add to the overall spectrum demand in this band, or do not represent MOD demand for spectrum.

3.9.2 2015 view

Band	Total Demand	MOD Demand, met within Supply	Apparent Spare Spectrum	Unavailable, Shared Spectrum	MOD Demand, in excess of Supply
3,100 to 3,400 MHz	175 MHz	175. MHz	125. MHz	---	---

No significant changes in systems or spectrum demand are foreseen between 2010 and 2015.

3.9.3 Band analysis

Geographic issues and potential for geographic sharing

It is clear from the maps above that there is a hot-spot of demand at Benbecula for use with aerial targets. Otherwise, across the UK, there is significantly less demand for spectrum in this band, giving the potential for widespread release of spectrum.

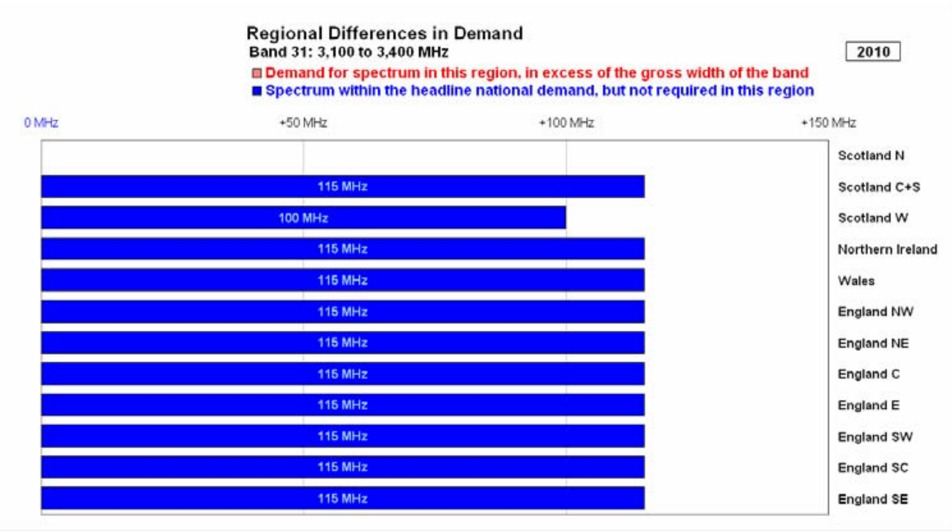


Figure 3-16: Differences in demand: 3100-3400MHz

Potential for spectrum release

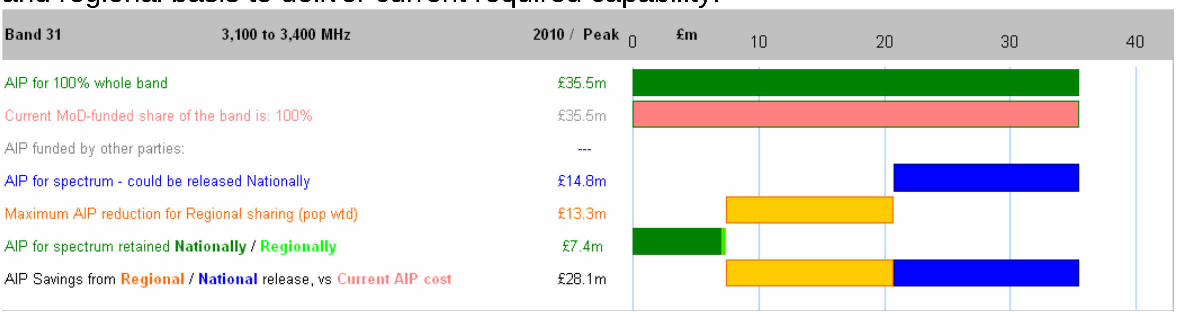
Even allowing for the localised use of spectrum at Benbecula, there is a significant amount of spectrum in this band that the MOD does not have a clear demand for (at least by 2010). That spectrum required at Benbecula may well be considered localised to such an extent that it would have minimal impact on an otherwise near national release of spectrum.

Other options for reducing spectrum requirement in this band

In this band we believe that there is very little possibility for sharing on a temporal basis.

Economic impact of demand

There appears to be potential for national release of spectrum within this band, with further opportunities for additional regional releases. The MOD is responsible for 100% of this band, but could save up to £28M p.a., while retaining enough spectrum on a national and regional basis to deliver current required capability.



3.9.4 Notes on Cave audit findings

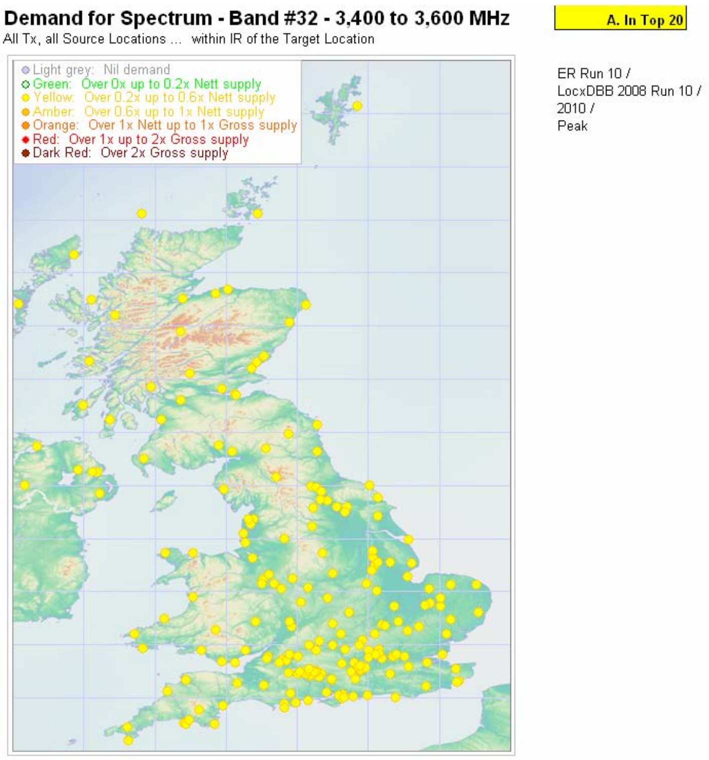
The Cave Audit reports on 2700-3400MHz as a single band, while this report splits this into two sub-bands.

Even taking this into account, this report sees greater opportunity for sharing or releasing spectrum in this band than the Cave Audit indicates. This is probably due to taking a view on 2010, when the T93 ASACS radars will be replaced by T102 radars. The T93 radars currently place a large demand for spectrum in this band, which will be removed by 2010.

3.10 BAND 32 : 3400MHZ – 3600MHZ

3.10.1 2010 view

Band	Total Demand	MOD Demand, met within Supply	Apparent Spare Spectrum	Unavailable, Shared Spectrum	MOD Demand, in excess of Supply
3,400 to 3,600 MHz	56 MHz	56. MHz	64. MHz	80. MHz	---



Overall usage

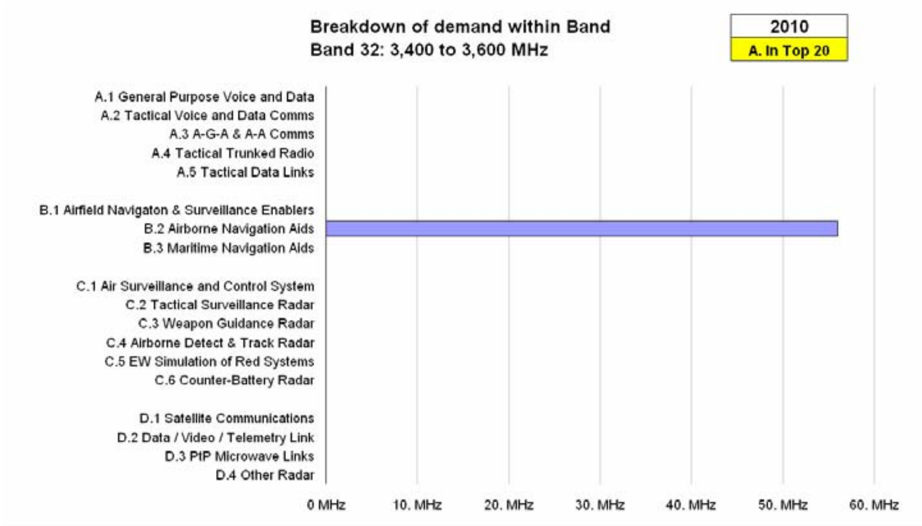


Figure 3-17: Demand for spectrum: 3400-3600MHz

This band shows a significant amount of spare spectrum at 64MHz.

Key systems in use

The only specific demand in this band is:

- Ubiquitous demand for Hercules SKE (Station Keeping Equipment) markers
  - We allow for a maximum of 14 Hercules aircraft expected to be together in UK for coordinated training exercise.

Opportunistic uses of band

There are some civil uses of this band, but we have not identified any additional MOD opportunistic users.

3.10.2 2015 View

Band	Total Demand	MOD Demand, met within Supply	Apparent Spare Spectrum	Unavailable, Shared Spectrum	MOD Demand, in excess of Supply
3,400 to 3,600 MHz	56 MHz	56. MHz	64. MHz	80. MHz	---

No significant changes in systems or spectrum demand are foreseen between 2010 and 2015.

3.10.3 Band analysis

Geographic issues and potential for geographic sharing

The maps above show an even demand for spectrum across the UK. This is because the Station Keeping Equipment is treated as a ubiquitous demand for spectrum.

In practice, the peak of demand above may only be required during very limited periods of time and in specific areas (e.g. Salisbury Plain). These practical limitations may mean that there are further possibilities for geographical sharing of spectrum beyond the spare spectrum shown at a total UK level.

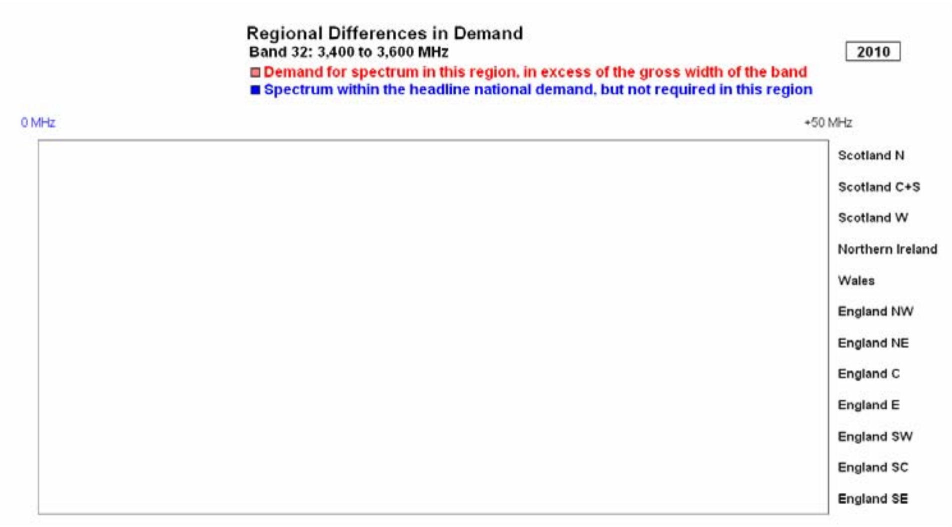


Figure 3-18: Differences in demand: 3400-3600MHz

Potential for spectrum release

There is already a significant amount of spectrum in this band being used by commercial interests. Even allowing for this though, there appears to be a large amount of further spectrum that the MOD does not have clear demand for in this band. Therefore, there should be a good opportunity to release further spectrum in this band on a national basis.

Other options for reducing spectrum requirement in this band

As mentioned above, in practice, the peak of demand above may only be required during very limited periods of time and in specific areas (e.g. Salisbury Plain). These periods of time may be small enough that there is a commercial value to the spectrum that is available for large periods of time.

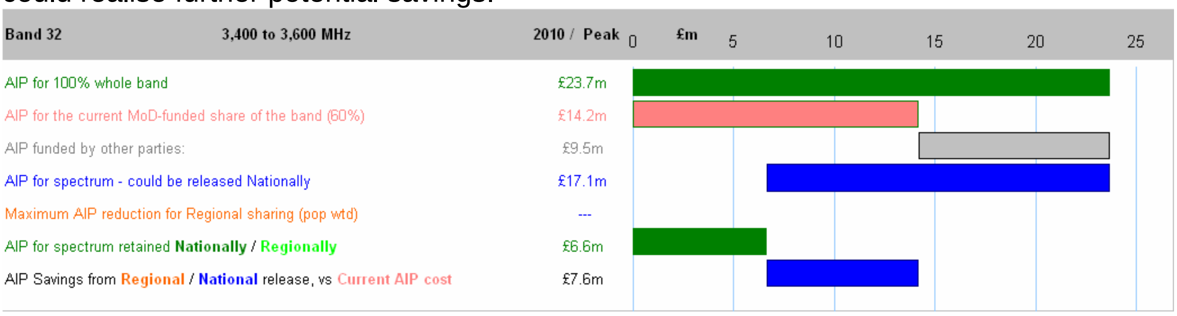
Given the potential commercial attractiveness of this band, it is worth considering whether these Hercules SKE markers could be re-banded into another band. This could effectively free up the entire band. From a technical point of view, this equipment and the function it carries out may well be equally feasible between 2700MHz – 3400MHz, or even at a higher operating frequency. Also, at an AIP cost of approximately £7M per annum, it is worthwhile questioning whether this capability is essential. We consider options for this equipment in section 5.

Economic impact of demand

As discussed above, there appears to be significant potential for national release of spectrum within this band.

The MOD currently pays 60% of the AIP for this whole band (£23.7M), due to existing sharing arrangements with other parties. However, further savings of nearly £3M p.a. could be realised, while retaining enough spectrum on a national and regional basis to deliver current required capability.

As discussed above, the actual use of equipment in this band may be more restricted on a geographic basis, or may have the potential to be moved into other bands. If so, this could realise further potential savings.



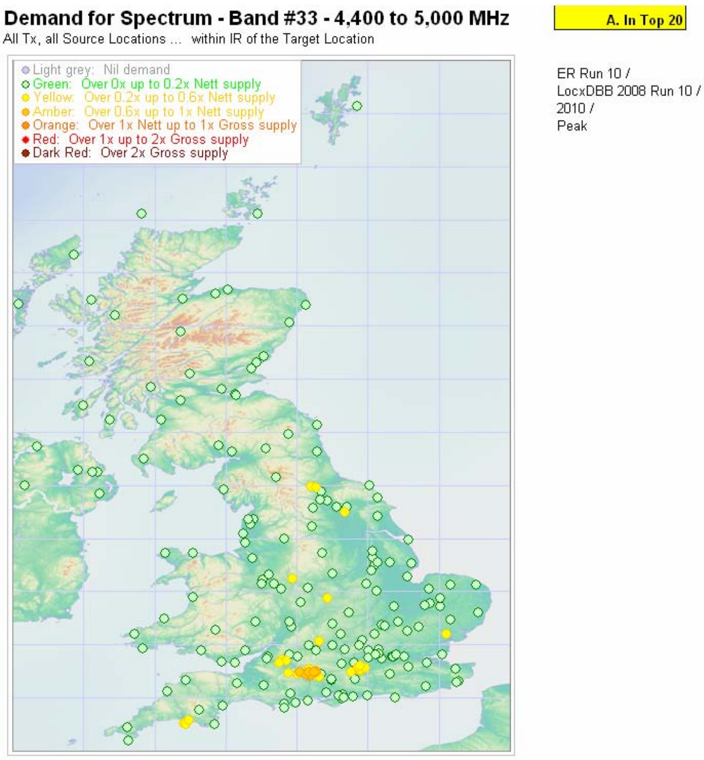
3.10.4 Notes on Cave audit findings

Overall, the findings of this report are in line with the Cave Audit findings, highlighting the potential for national release of spectrum from within this band.

3.11 BAND 33 : 4400MHZ – 5000MHZ

3.11.1 2010 view

Band	Total Demand	MOD Demand, met within Supply	Apparent Spare Spectrum	Unavailable, Shared Spectrum	MOD Demand, in excess of Supply
4,400 to 5,000 MHz	477 MHz	477. MHz	123. MHz	---	---



Overall usage

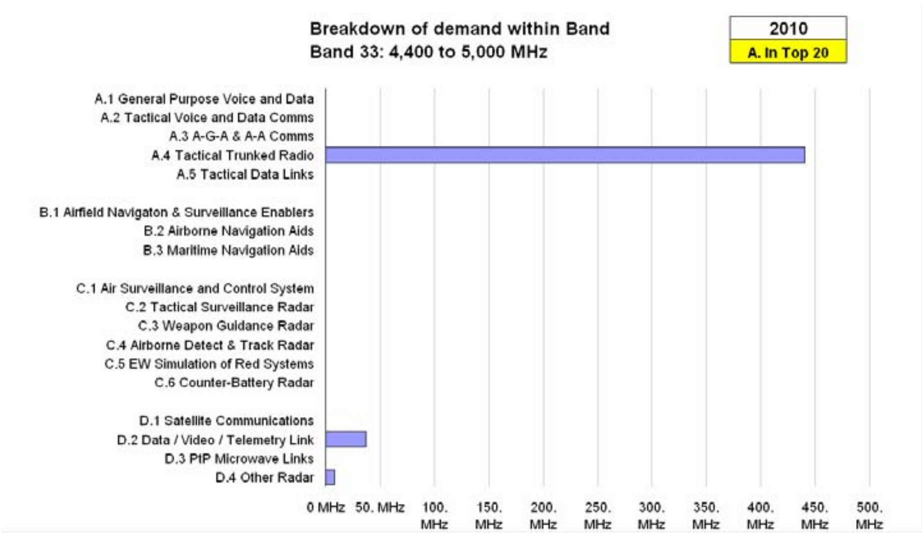


Figure 3-19: Demand for spectrum: 4400-5000MHz

This band shows a significant amount of spare spectrum at 123MHz.

Key systems in use

There is significant spectrum demand from:

- Ptarmigan trunked radio (note that Cormorant does not operate in this band).
- FALCON trunked radio
  - FALCON is due to come into service in 2010, using 20MHz channels in this band. This will result in significantly greater spectrum demand for FALCON trunked radio in this band, compared to today's demand from Ptarmigan.
- Long-Range Bearer (LRB)
  - Details of how LRB is used in the UK were not available at the date of this report.
- Ubiquitous demand for the Sniper pod downlink.

Opportunistic uses of band

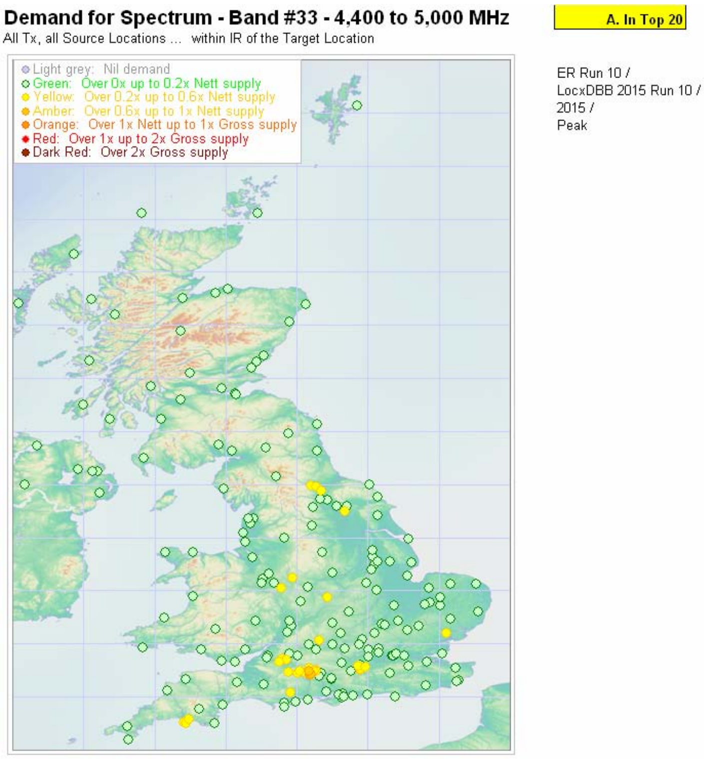
Other opportunistic users in the band, which have not been explicitly included in our modelling for this band, include:

- Some fixed microwave links
- Some EW calibration to ships.

It is felt that these systems are so localised that they are not likely to add to the overall spectrum demand in this band.

3.11.2 2015 view

Band	Total Demand	MOD Demand, met within Supply	Apparent Spare Spectrum	Unavailable, Shared Spectrum	MOD Demand, in excess of Supply
4,400 to 5,000 MHz	429 MHz	429. MHz	171. MHz	---	---



This band actually sees a reduction in forecast demand (of 48MHz) by 2015. The main changes from 2010 are:

- Ptarmigan trunked radio will be out of service, while FALCON will have the same demand as for the 2010 view above. Cormorant does not operate in this band, so the Ptarmigan demand simply drops out completely by 2015.
- Due to changes in, and movements between, locations between 2010 and 2015, there is also a slight increase in the forecast spectrum demand from use of Long Range Bearer.
- As noted above, details of how LRB is used in the UK were not available at the date of this report.

3.11.3 Band analysis

Geographic issues and potential for geographic sharing

From the maps above, it can be seen that there is a hot-spot of demand around Salisbury Plain. This is expected given the main demand in this band is from tactical trunked radio systems, which will be heavily used during major exercises in Salisbury Plain.

This gives the potential for geographic sharing and release of spectrum, given the large areas of the UK where the spectrum demand is significantly less than that in Salisbury Plain.

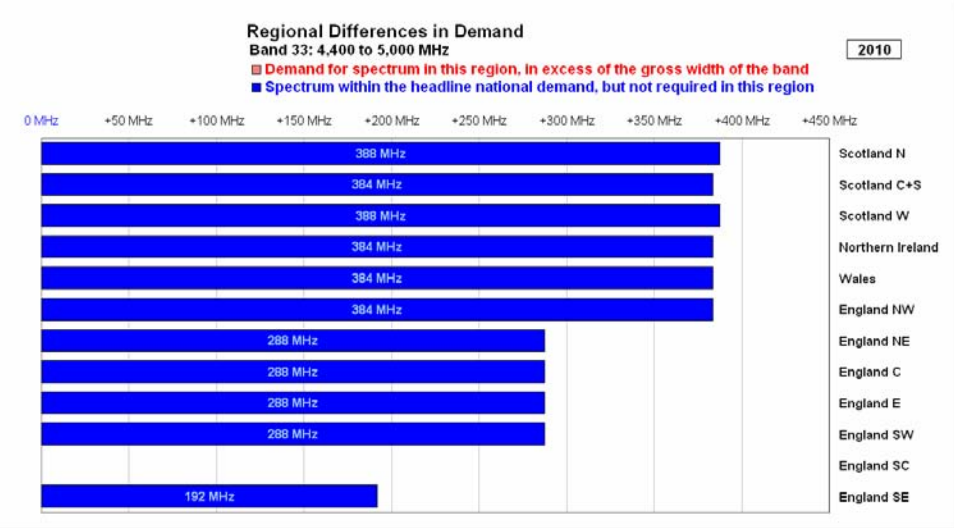


Figure 3-20: Differences in demand: 4400-5000MHz

Potential for spectrum release

This band shows good potential for national release of spectrum. There is a significant amount of spectrum not used in this band and, as noted below, there may be options for further reducing the peak demand in-band.

Other options for reducing spectrum requirement in this band

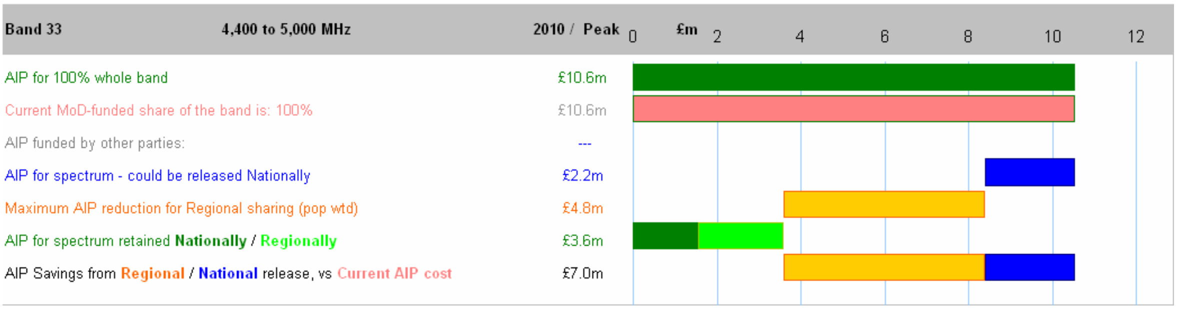
We model Ptarmigan and FALCON running in parallel in this band for 2010, with their demand for spectrum adding to each other (as opposed to one immediately replacing the other). While FALCON is replacing Ptarmigan and has an in-service date of 2010, Ptarmigan will be used for a further couple of years.

- There is the potential to reduce spectrum demand further in this band if Ptarmigan and FALCON can be treated as alternative systems demanding the same spectrum, rather than adding their separate demands.

Given the directionality of these trunked radio links, it is also possible that we have over-estimated the level of interference that will be suffered between locations. A more detailed study into the practical spectrum requirements of training with trunked radio systems could lead to further potential for reducing spectrum demand in this band.

Economic impact of demand

There appears to be good potential for national release of spectrum within this band, with significant further opportunities for additional regional releases. MOD is responsible for 100% of this band, but could save up to £7M p.a., while retaining enough spectrum on a national and regional basis to deliver current required capability.



3.11.4 Notes on Cave audit findings

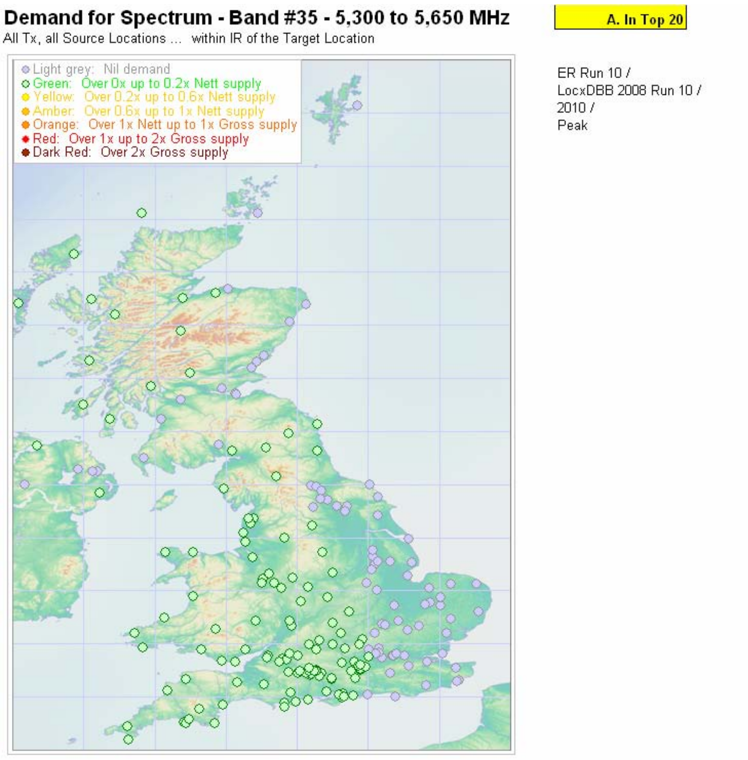
Overall, the findings of this report are in line with the Cave Audit findings, highlighting the potential for national release of spectrum from within this band.

Furthermore, this report highlights the potential for further geographic sharing due to the localised nature of hot-spots of demand, particularly training on tactical trunked radio links on Salisbury Plain.

3.12 BAND 35 : 5300MHZ – 5650MHZ

3.12.1 2010 view

Band	Total Demand	MOD Demand, met within Supply	Apparent Spare Spectrum	Unavailable, Shared Spectrum	MOD Demand, in excess of Supply
5,300 to 5,650 MHz	46 MHz	46. MHz	304. MHz	---	---



Overall usage

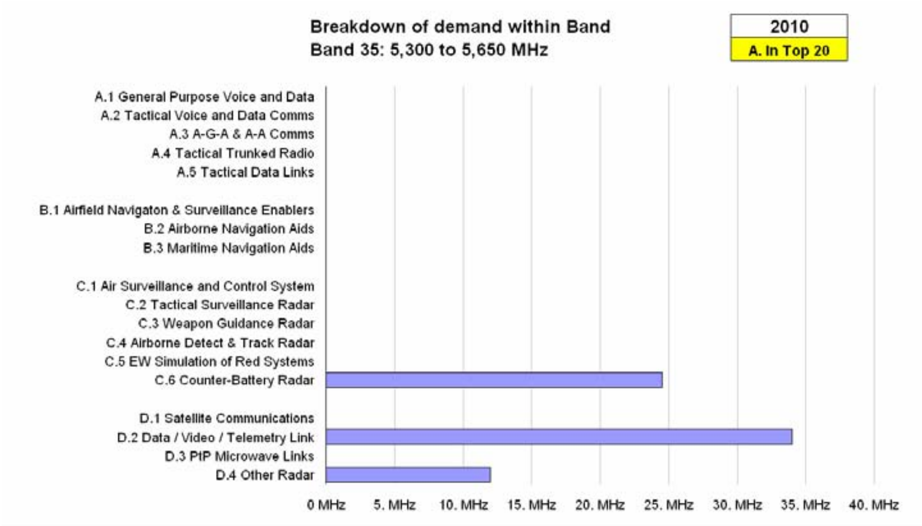


Figure 3-21: Demand for spectrum: 5300-5650MHz

This band shows a significant amount of spare spectrum at 304MHz.

Key systems in use

There is significant spectrum demand from:

- MOTR range safety radar (split with Band 36 below)
- BRIMSTONE and BVRAAM data / telemetry links at Benbecula
- COBRA and MAMBA counter-battery radars
  - MAMBA spectrum demand is split with Band 36 below.

Opportunistic uses of band

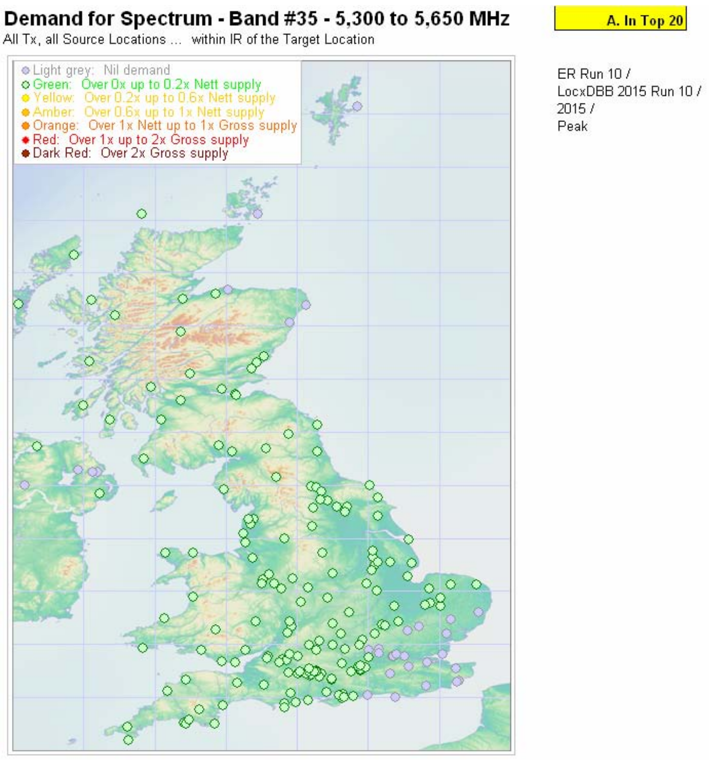
Other opportunistic users in the band, which have not been explicitly included in our modelling for this band, include:

- Some Met Office weather radars
- Vehicle Location System on Salisbury Plain

It is felt that these systems are either so localised that they are not likely to add to the overall spectrum demand in this band, or do not represent MOD demand for spectrum.

3.12.2 2015 view

Band	Total Demand	MOD Demand, met within Supply	Apparent Spare Spectrum	Unavailable, Shared Spectrum	MOD Demand, in excess of Supply
5,300 to 5,650 MHz	46 MHz	46. MHz	304. MHz	---	---



No significant changes in systems or spectrum demand are foreseen between 2010 and 2015.

It should be noted that the 2015 map for spectrum demand in this band shows some changes on a geographical basis from the 2010 map. However, this does not change the overall demand within the band.

3.12.3 Band analysis

Geographic issues and potential for geographic sharing

It can be seen from the maps above, that while demand for spectrum in this band is scattered around the UK (more so in the 2015 picture), there are large areas of the UK where spectrum demand is minimal. Therefore there is real potential for geographical sharing of spectrum in this band.

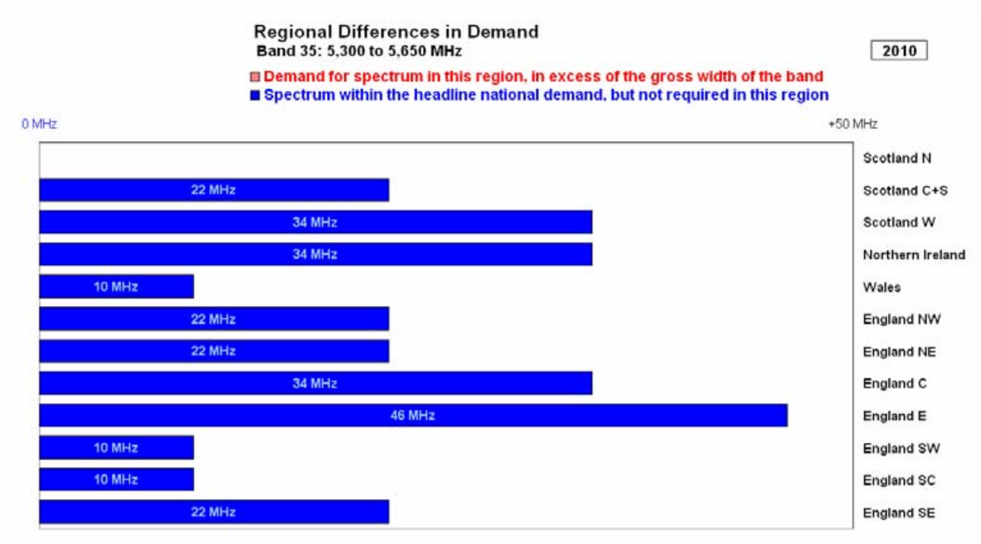


Figure 3-22: Differences in demand: 5300-5650MHz

Potential for spectrum release

Clearly, there is a large amount of spectrum in this band for which the MOD does not have a clear requirement. On this basis, there is a good prospect of being able to release spectrum in this band on a national basis.

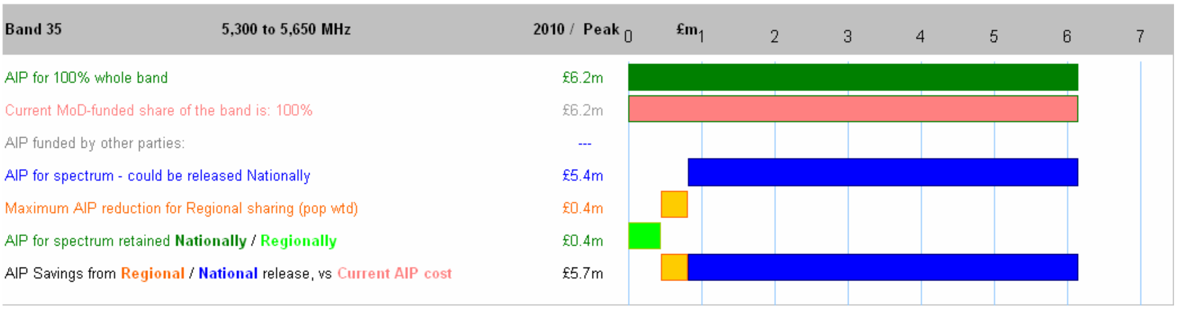
Other options for reducing spectrum requirement in this band

A detailed demand study of COBRA and MAMBA training and testing usage could deliver further savings in this band, if their spectrum demand could be shared across time and geography, giving better re-use of frequencies across the two systems.

It can be noted that some of the systems in this band (MOTR, MAMBA) are also present in other adjacent bands. It may be worth studying the potential for consolidating these systems into a single band in order to free up spectrum further.

Economic impact of demand

There appears to be significant potential for national release of spectrum within this band, with some further opportunities for additional regional releases. The MOD is responsible for 100% of this band, but could save £5.8M p.a., while retaining enough spectrum on a national and regional basis to deliver current required capability.



3.12.4 Notes on Cave audit findings

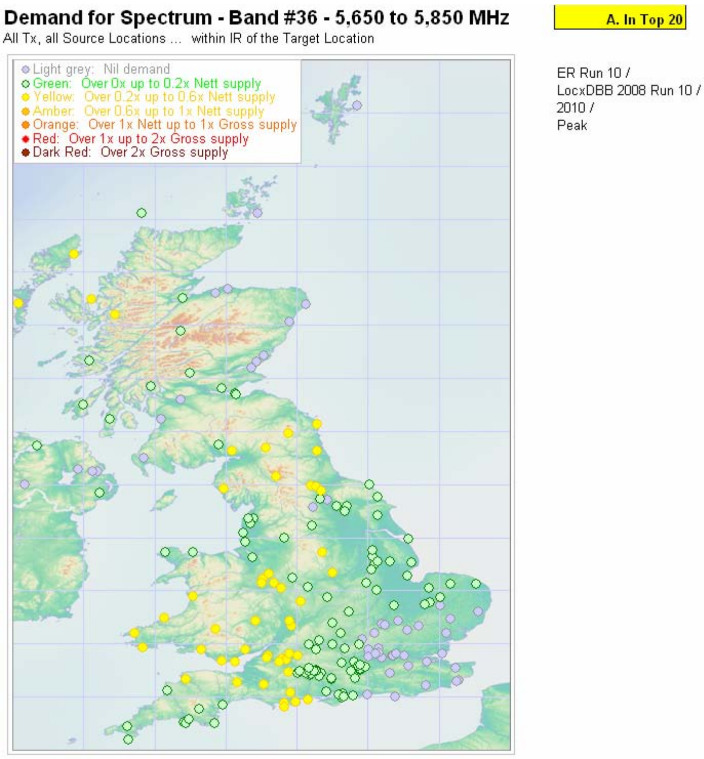
The Cave Audit reports on 5000-5850MHz as a single band, while this report splits this into two sub-bands.

Even taking this into account, this report sees greater opportunity for sharing or releasing spectrum in this band than the Cave Audit indicates. Only limited MOD uses of this band have been identified and these are restricted to particular locations (rather than nation-wide use of spectrum). This raises the potential for both national and geographic sharing or release of spectrum in this band.

3.13 BAND 36 : 5650MHZ – 5850MHZ

3.13.1 2010 view

Band	Total Demand	MOD Demand, met within Supply	Apparent Spare Spectrum	Unavailable, Shared Spectrum	MOD Demand, in excess of Supply
5,650 to 5,850 MHz	49 MHz	48.8 MHz	51.2 MHz	100. MHz	---



Overall usage

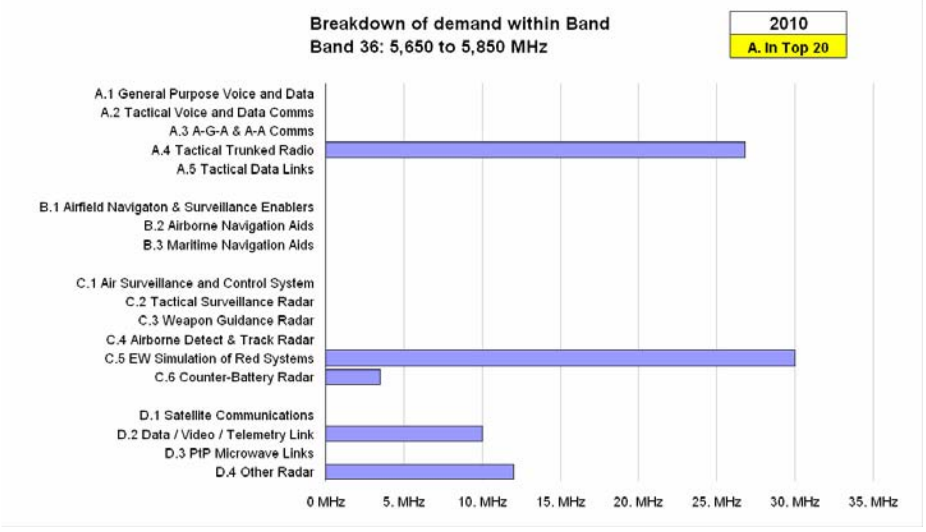


Figure 3-23: Demand for spectrum: 5650-5850MHz

This band shows a significant amount of spare spectrum at 51MHz.

Key systems in use

There is significant spectrum demand from:

- MOTR range safety radar (split with Band 35 above)
- MAMBA counter-battery radars (split with Band 35 above)
- Some EW simulation (SA-6 search radars)
- Aerial target transponder (Mirach)
- Some special systems
  - These systems may well be able to co-exist with other systems in the band and may not actually contribute to the overall demand in band.

The systems above are scattered around a few different sites and some do not interfere with other sites (e.g. aerial targets don't interfere with EW simulation).

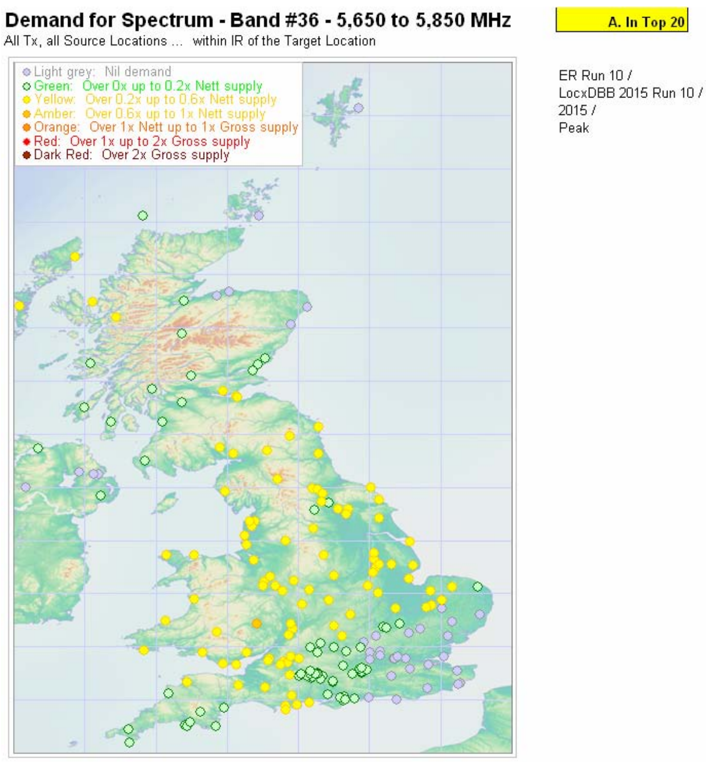
Opportunistic uses of band

- We have not identified any other MOD opportunistic users of this band.

These systems do not represent MOD demand for spectrum.

3.13.2 2015 view

Band	Total Demand	MOD Demand, met within Supply	Apparent Spare Spectrum	Unavailable, Shared Spectrum	MOD Demand, in excess of Supply
5,650 to 5,850 MHz	61 MHz	60.8 MHz	39.2 MHz	100. MHz	---



This band sees a slight increase of 12MHz in demand by 2015. The main change from 2010 is:

- Due to changes in, and movements between, locations between 2010 and 2015, there is an increase in the forecast spectrum demand from use of MOTR range safety radar.

3.13.3 Band analysis

Geographic issues and potential for geographic sharing

From the maps above, the demand for spectrum in this band is scattered across large areas of the UK. This has allowed for a level of frequency re-use between different systems in different locations to already be taken into account.

Even so, there are regions (e.g. South-East England), where demand is noticeably less than in other areas. Therefore, there is the potential for specific regional or geographic sharing of spectrum.

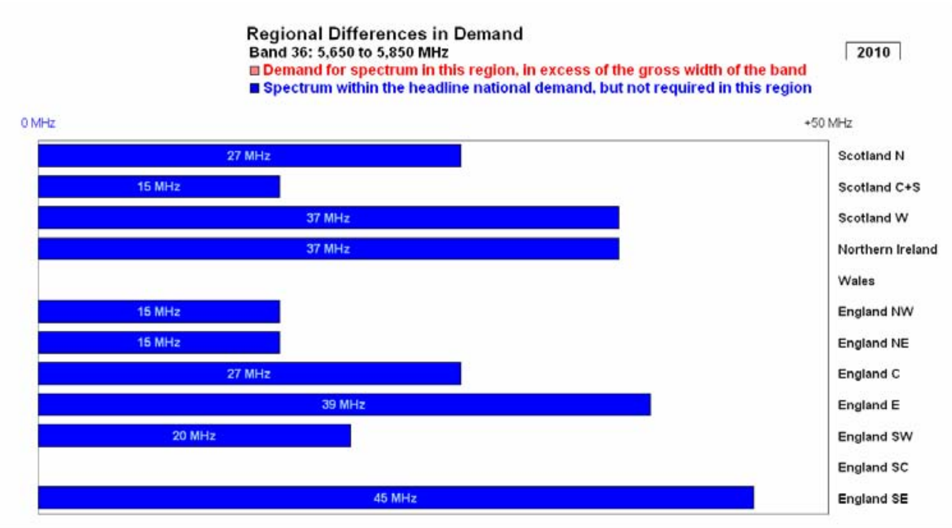


Figure 3-24: Differences in demand: 5650-5850MHz

Potential for spectrum release

The MOD already effectively shares spectrum with other users in this band. Even allowing for this though, there is apparent spare spectrum for which the MOD does not have a clear demand. This raises the potential for a national release of spectrum within this band.

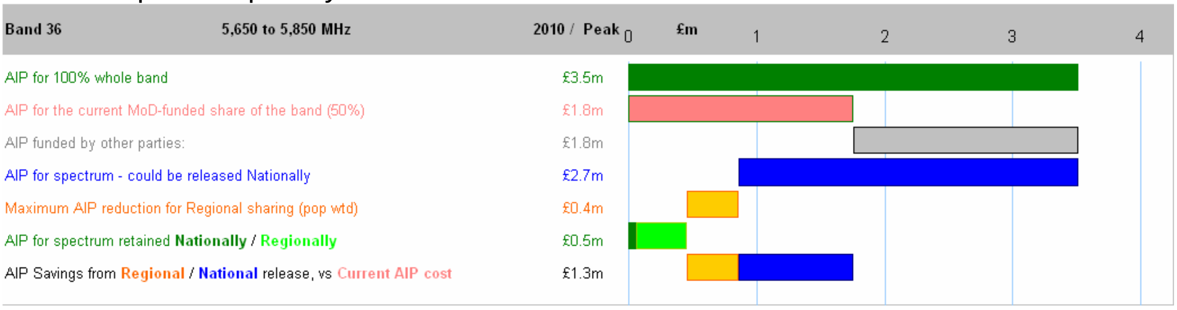
Other options for reducing spectrum requirement in this band

It can be noted that some of the systems in this band (MOTR, MAMBA) are also present in other adjacent bands. It may be worth studying the potential for consolidating these systems into a single band in order to free up spectrum further.

Economic impact of demand

There appears to be good potential for national release of spectrum within this band, with some further opportunities for additional regional releases.

The MOD currently pays 50% of the AIP for this whole band (£3.5M p.a.), but could save £1.4M p.a., while retaining enough spectrum on a national and regional basis to deliver current required capability.



3.13.4 Notes on Cave audit findings

The Cave Audit reports on 5000-5850MHz as a single band, while this report splits this into two sub-bands.

Even taking this into account, this report sees greater opportunity for sharing or releasing spectrum in this band than the Cave Audit indicates. Only limited MOD uses of this band have been identified and these are restricted to particular locations (rather than nation-wide use of spectrum). This raises the potential for both national and geographic sharing or release of spectrum in this band.

3.14 BAND 37: 7250MHZ – 7400MHZ

3.14.1 2010 view

Band	Total Demand	MOD Demand, met within Supply	Apparent Spare Spectrum	Unavailable, Shared Spectrum	MOD Demand, in excess of Supply
7,250 to 7,400 MHz	151 MHz	150. MHz	---	---	0.5 MHz

This band is used for Skynet downlink transmissions with several ground stations around the UK. Since interference considerations for satellite systems are dealt with differently to ground systems, the interference map shown in other sections is not included here.

Overall usage

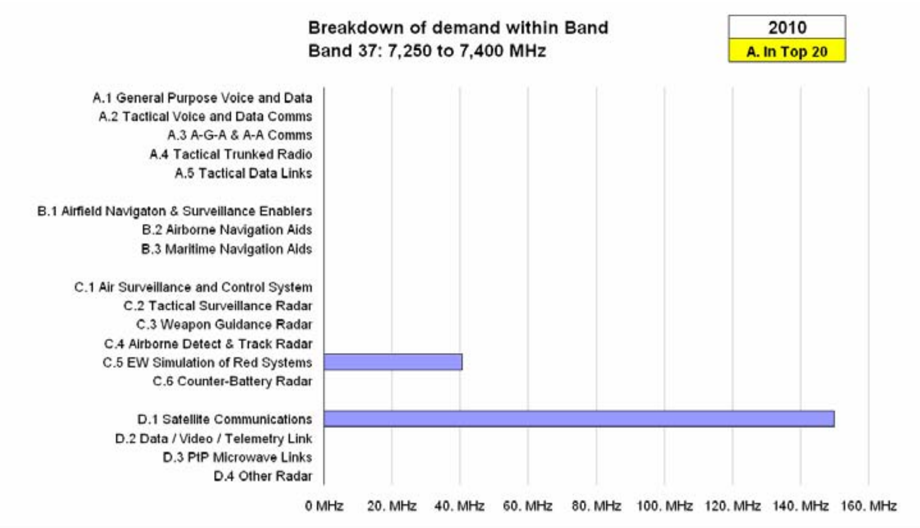


Figure 3-25: Demand for spectrum: 7250-7400MHz

This band appears as having demand just exceeding capacity. This is primarily due to this being a sub-band of the 500MHz used as a Skynet downlink band and our approach allocates a proportional amount of this demand to this sub-band.

- In practice, our consideration of this band could be expanded to 7250MHz – 7750MHz to accurately reflect the Skynet allocation

Key systems in use

As noted above, the main systems in use in this band are satellite communications systems using the Skynet band.

There is also some localised demand for EW simulation at Spadeadam in this band.

Opportunistic uses of band

No opportunistic users of this band have been identified.

3.14.2 2015 view

Band	Total Demand	MOD Demand, met within Supply	Apparent Spare Spectrum	Unavailable, Shared Spectrum	MOD Demand, in excess of Supply
7,250 to 7,400 MHz	151 MHz	150. MHz	---	---	0.5 MHz

As for 2010, the interference map shown in other sections is not included here.

No significant changes in systems or spectrum demand are foreseen between 2010 and 2015.

3.14.3 Band analysis

Geographic issues and potential for geographic sharing

As this is satellite downlink, in practice the downlink transmission footprint will cover the entire UK. From the point of view of potential interference, the transmission to any point in the UK will cause interference across the UK.

For this reason, it is likely that sharing spectrum in this band on a geographic basis may well not be feasible.

Potential for spectrum release

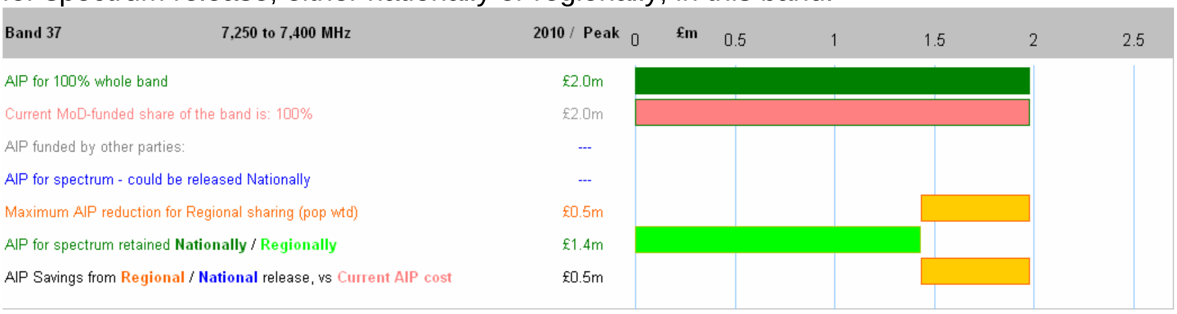
As for Band 37 above, given the long term Skynet service provision of satellite communications in this band, there seems no likely prospect of a national release of spectrum in this band within the next ten years.

Other options for reducing spectrum requirement in this band

None identified.

Economic impact of demand

As discussed above, this is the satellite comms downlink band, with a UK-wide footprint and with long-term Skynet service provision. As such, there is unlikely to be any potential for spectrum release, either nationally or regionally, in this band.



3.14.4 Notes on Cave audit findings

The Cave Audit does not explicitly report on this band.

3.15 BAND 40 : 8025MHZ – 8400MHZ

3.15.1 2010 view

Band	Total Demand	MOD Demand, met within Supply	Apparent Spare Spectrum	Unavailable, Shared Spectrum	MOD Demand, in excess of Supply
8,025 to 8,400 MHz	385 MHz	375. MHz	---	---	10. MHz

This band is used for Skynet uplink transmissions with several ground stations around the UK. Since interference considerations for satellite systems are dealt with differently to ground systems, the interference map shown in other sections is not included here.

Overall usage

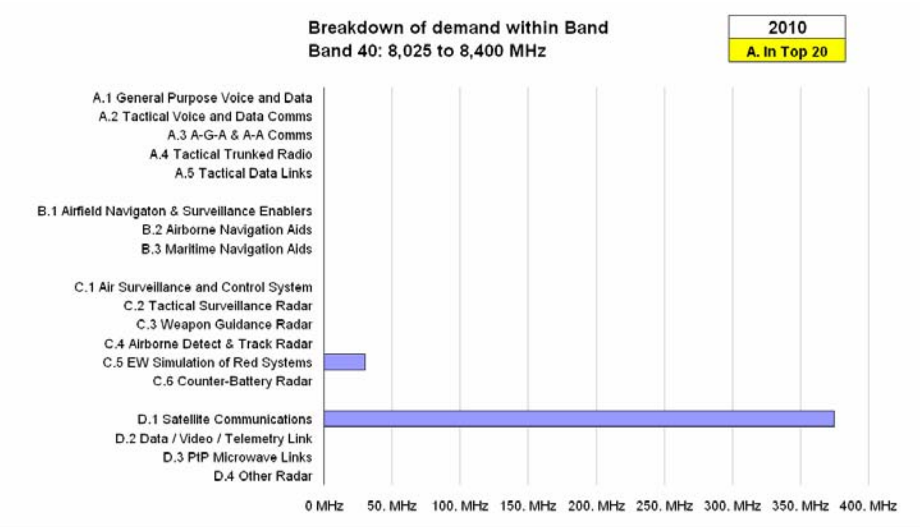


Figure 3-26: Demand for spectrum: 8025-8400MHz

This band appears as having demand just exceeding capacity. This is primarily due to this being a sub-band of the 500MHz Skynet satellite communications uplink band and our approach allocates a proportional amount of this demand to this sub-band.

- In practice, our consideration of this band could be expanded to 7900MHz – 8400MHz to accurately reflect the Skynet allocation.

Key systems in use

As noted above, the main systems in use in this band are satellite communications systems using the Skynet band.

There is also some EW simulation in this band, at Spadeadam and other minor EW simulation sites.

Opportunistic uses of band

Other opportunistic users in the band, which have not been explicitly included in our modelling for this band, include:

- Some fixed microwave links
- Some ship / shore communications.

It is felt that these systems are so localised that they are not likely to add to the overall spectrum demand in this band.

3.15.2 2015 view

Band	Total Demand	MOD Demand, met within Supply	Apparent Spare Spectrum	Unavailable, Shared Spectrum	MOD Demand, in excess of Supply
8,025 to 8,400 MHz	385 MHz	375. MHz	---	---	10. MHz

As for 2010, the interference map shown in other sections is not included here.

No significant changes in systems or spectrum demand are foreseen between 2010 and 2015.

3.15.3 Band analysis

Geographic issues and potential for geographic sharing

In practice, satellite communications may be transmitted from a much larger range of locations than fixed earth stations, as transportable satellite terminals may use this band.

It is likely that sharing spectrum in this band on a geographic basis may well not be feasible.

Potential for spectrum release

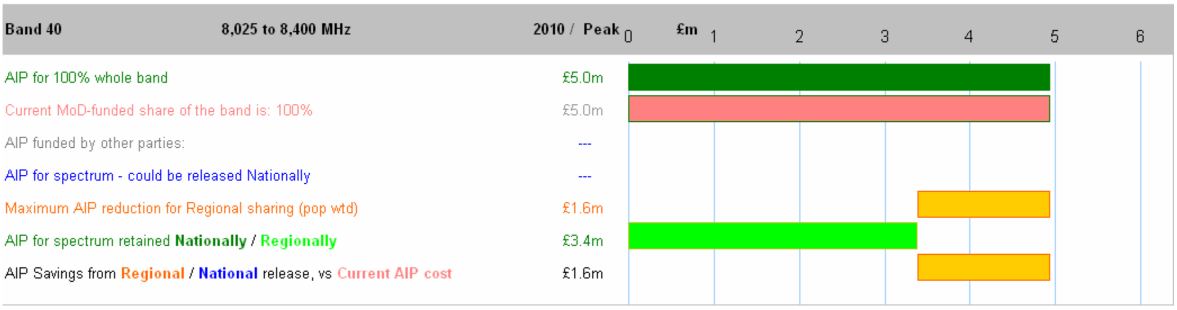
As for Band 37 above, given the long term Skynet service provision of satellite communications in this band, there seems no likely prospect of a national release of spectrum in this band within the next ten years.

Other options for reducing spectrum requirement in this band

None identified.

Economic impact of demand

As discussed above, this is the satellite comms uplink band, with a UK-wide footprint and with long-term Skynet service provision. As such, there is unlikely to be any potential for spectrum release, either nationally or regionally, in this band.



3.15.4 Notes on Cave audit findings

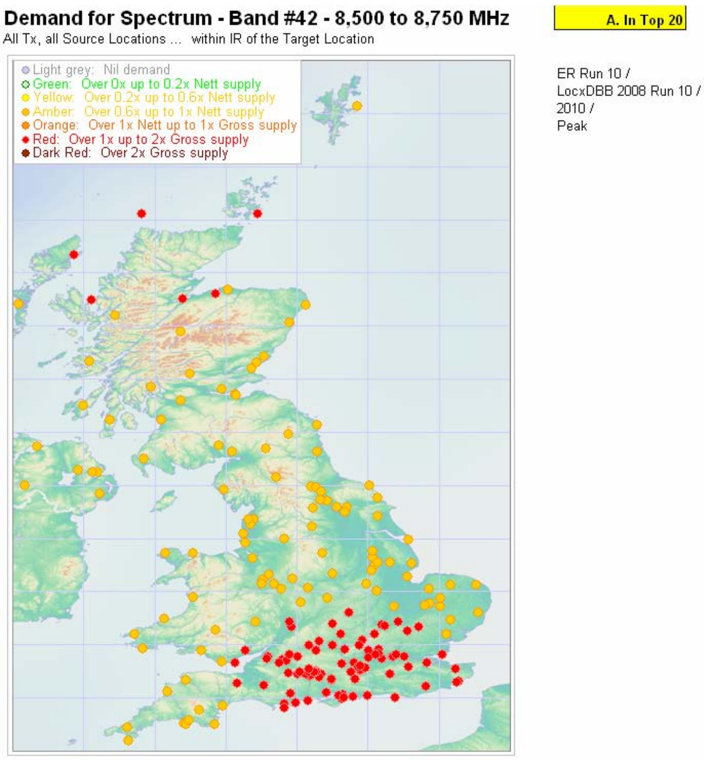
The Cave Audit findings on this band state "…it appears that the nature of UK use of this band is fixed and that there should therefore be scope for geographical sharing in this band."

As indicated above, this report suggests that geographical sharing may be difficult due to the nature of MOD use of satellite communications in this band may be very widespread with transportable terminals in use at training areas at other MOD locations.

3.16 BAND 42 : 8500MHZ – 8750MHZ

3.16.1 2010 view

Band	Total Demand	MOD Demand, met within Supply	Apparent Spare Spectrum	Unavailable, Shared Spectrum	MOD Demand, in excess of Supply
8,500 to 8,750 MHz	254 MHz	250. MHz	---	---	4. MHz



Overall usage

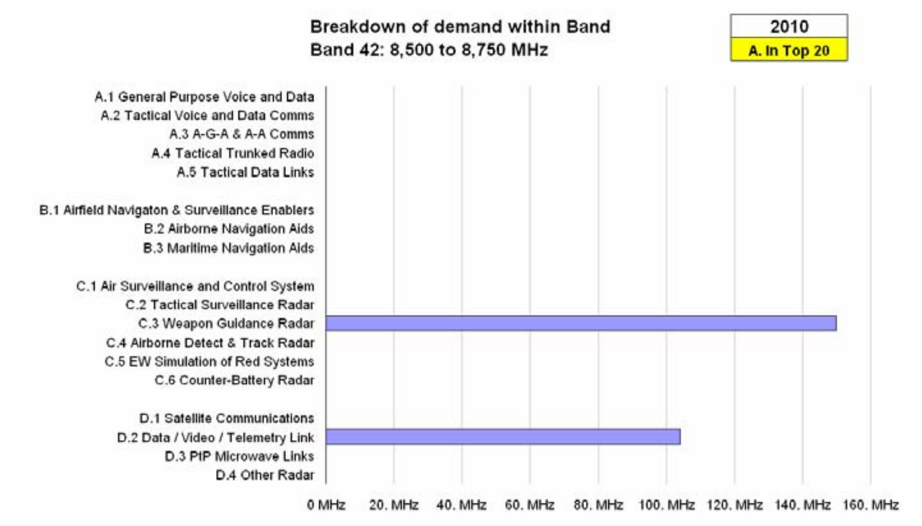


Figure 3-27: Demand for spectrum: 8500-8750MHz

This band shows a slight over-demand for spectrum.

Key systems in use

There is significant spectrum demand in this band from:

- Some Naval radars – T909, T911 Seawolf Fire Control.
- Some details for these radars were not available at the date of this report, with the potential for subsequent impact on the results for this band. However, as this band already appears over-subscribed, it seems unlikely that changes in the technical parameters for some systems will change that overall picture.
- Nimrod video link.

It is worth noting that some of the airborne and naval radars can operate between 8500MHz – 10000MHz. In the modelling for this report, such systems are allocated to specific bands, but in practice the spectrum demand for these systems may be spread across some or all of the sub-bands in this range.

Opportunistic uses of band

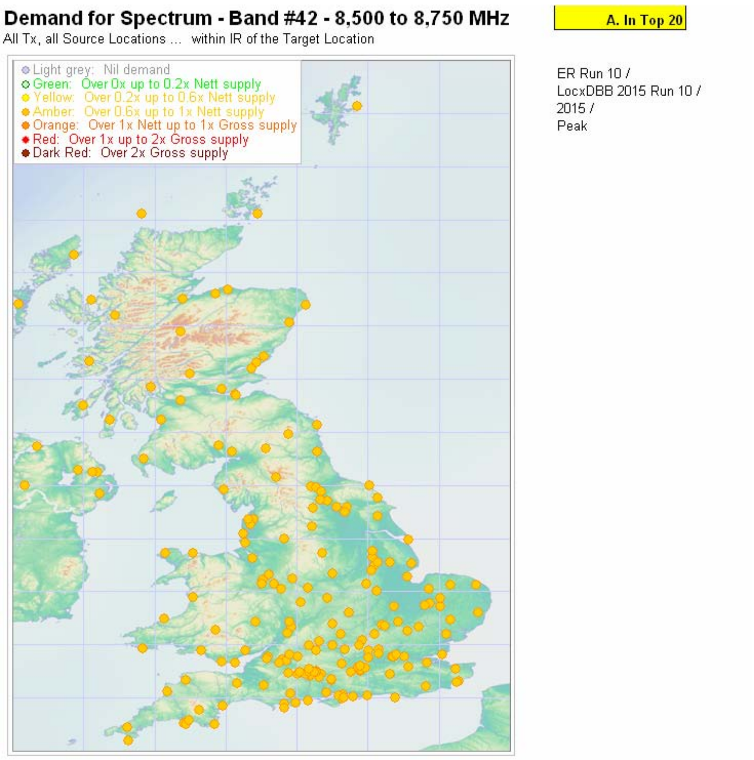
Other opportunistic users in the band, which have not been explicitly included in our modelling for this band, include:

- Some fixed microwave links
- Some video transmission in Northern Ireland.

It is felt that these systems are so localised that they are not likely to add to the overall spectrum demand in this band.

3.16.2 2015 view

Band	Total Demand	MOD Demand, met within Supply	Apparent Spare Spectrum	Unavailable, Shared Spectrum	MOD Demand, in excess of Supply
8,500 to 8,750 MHz	224 MHz	224. MHz	26. MHz	---	---



This band sees a drop of 30MHz in forecast demand by 2015. The main change from 2010 is:

The T909 radar is only used on T42 destroyers and therefore demand for this system drops out by 2015. This accounts for the entire drop of 30MHz in forecast demand.

3.16.3 Band analysis

Geographic issues and potential for geographic sharing

Note that a large proportion of the demand for the systems above is treated as ubiquitous, although in practice transmission will only be at sea. Furthermore, at these higher frequencies, operating ranges of these systems will be significantly lower than for the longer-range radars at 3GHz and below.

- There may therefore be an opportunity for geographical sharing of spectrum in this band, particularly inland where the systems above will not be transmitting. However, on a regional basis, almost all regions will have coastline, and all regions will have major population centres within interference range of the sea, so sea-based transmissions will affect all regions.

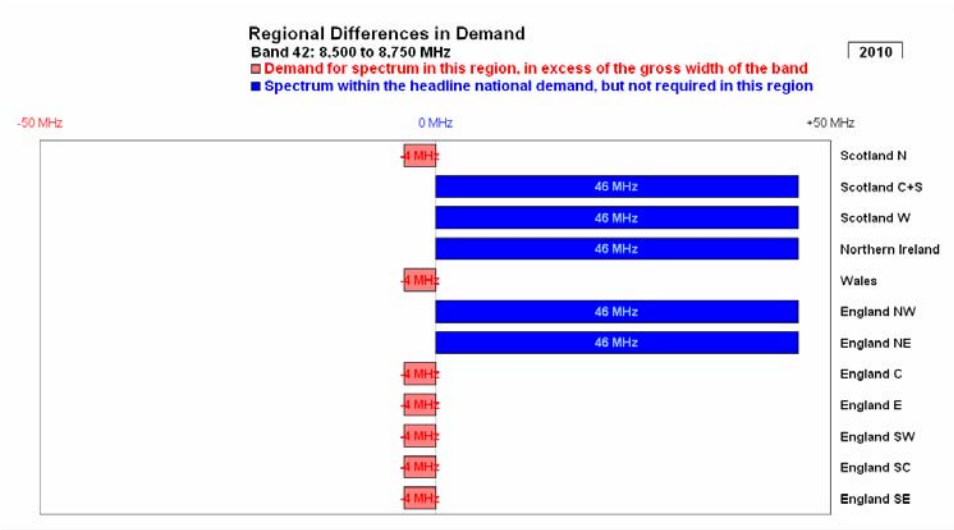


Figure 3-28: Differences in demand: 8500-8750MHz

Potential for spectrum release

This band represents part of a very busy area of spectrum between 8500MHz – 10000MHz. Looking across that wider band and within this band itself, there seems little prospect of a national release of spectrum in this band.

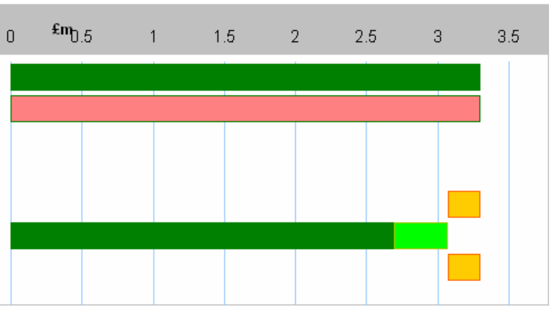
Other options for reducing spectrum requirement in this band

As noted for Band 30 (2700MHz – 3100MHz), we currently assume that surveillance and weapons radars need to be deconflicted using different channels. If, in practice, this deconfliction can be achieved using pulse profiling (or other techniques) to differentiate radar transmissions in the same channel, this will reduce the number of channels needed and therefore reduce the total spectrum demand in this band.

Economic impact of demand

There appears to be some small potential for regional release of spectrum within this band (to a value of £0.2M p.a.). As discussed above, this band is part of a very busy band of spectrum from 8.5GHz to 10GHz and it may not feasible for the MOD to release any spectrum here.

Band 42	8,500 to 8,750 MHz	2010 / Peak
AIP for 100% whole band		£3.3m
Current MoD-funded share of the band is: 100%		£3.3m
AIP funded by other parties:		---
AIP for spectrum - could be released Nationally		---
Maximum AIP reduction for Regional sharing (pop wtd)		£0.2m
AIP for spectrum retained **Nationally** / **Regionally**		£3.1m
AIP Savings from **Regional** / **National** release, vs Current AIP cost		£0.2m



3.16.4 Notes on Cave audit findings

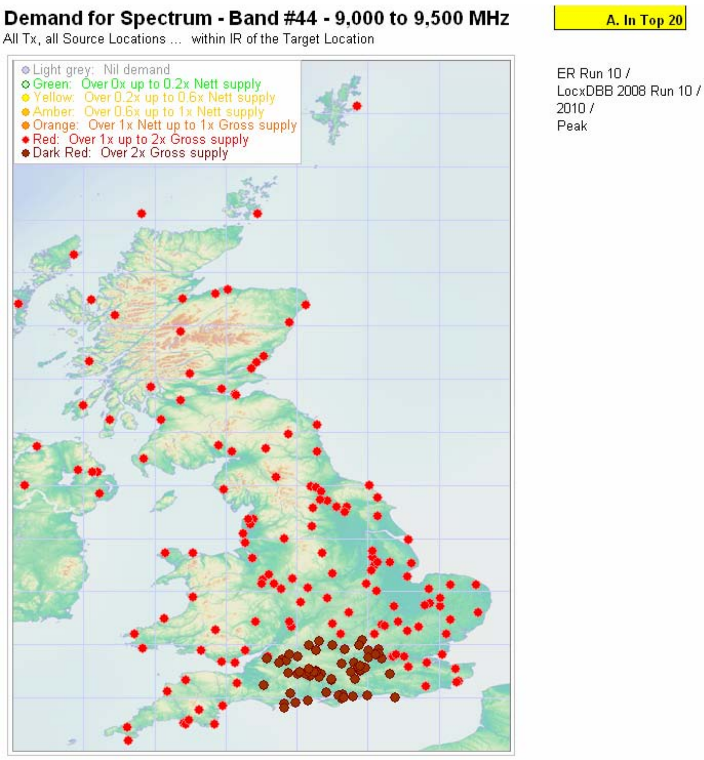
The Cave Audit reports on 8500-10500MHz (excluding 9000-9500MHz) as a single band. This report looks at separate sub-bands within this.

Overall, the Cave Audit suggests that there is good scope for releasing or sharing spectrum in this band. This report finds that there is significant spectrum demand from the MOD systems above, both within this band and across the wider 8500MHz – 10125MHz.

3.17 BAND 44 : 9000MHZ – 9500MHZ

3.17.1 2010 view

Band	Total Demand	MOD Demand, met within Supply	Apparent Spare Spectrum	Unavailable, Shared Spectrum	MOD Demand, in excess of Supply
9,000 to 9,500 MHz	1129 MHz	500. MHz	---	---	629.3 MHz



Overall usage

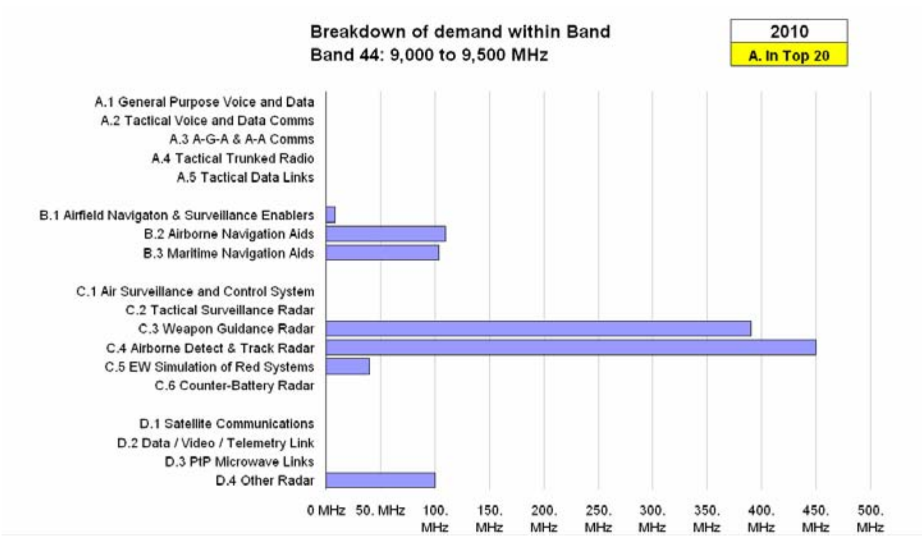


Figure 3-29: Demand for spectrum: 9000-9500MHz

This band shows massive over-demand for the available capacity.

However, there are a lot of systems that are allocated to this band by default (e.g. we may only know the operating frequency as 8GHz – 10GHz).

In practice, some of these systems may operate in adjacent bands, spreading the total demand across a wider band of spectrum. However, the adjacent bands have little or no spare spectrum, so this is not a clear solution for the over-demand.

Key systems in use

Large specific demands in this band are from:

- Ubiquitous demand for Tornado Foxhunter AI24 radar
  - This system presents enough demand to occupy almost the entire band on its own.
- Ubiquitous demand for weather radars on air transport squadrons
  - These radars are currently assumed to need their own individual channels. However, if these weather radars do not need to deconflict channels, then this will reduce spectrum demand in this band by ~100MHz.
- A range of Naval radars and Helicopter weapons radars, where the helicopters are associated with ships.
  - T1007, Goalkeeper, Seaspray, Blue Kestrel
- Aircraft / Missile tracking radars at training areas.
- EW simulation at Spadeadam and at other minor EW simulation sites
- Harbour maritime radars.

Some details for the radars above were not available at the date of this report, with the potential for subsequent impact on the results for this band. However, as this band already appears over-subscribed, it seems unlikely that changes in the technical parameters for some systems will change that overall picture.

A large proportion of the spectrum demand above is ubiquitous, either airborne (as indicated above) or from the naval radars at sea (in Task Groups).

Realistically there is probably a considerable excess in demand which has to be managed by operational spectrum managers. In practice, spectrum demand will be managed on both a geographic and time basis.

Opportunistic uses of band

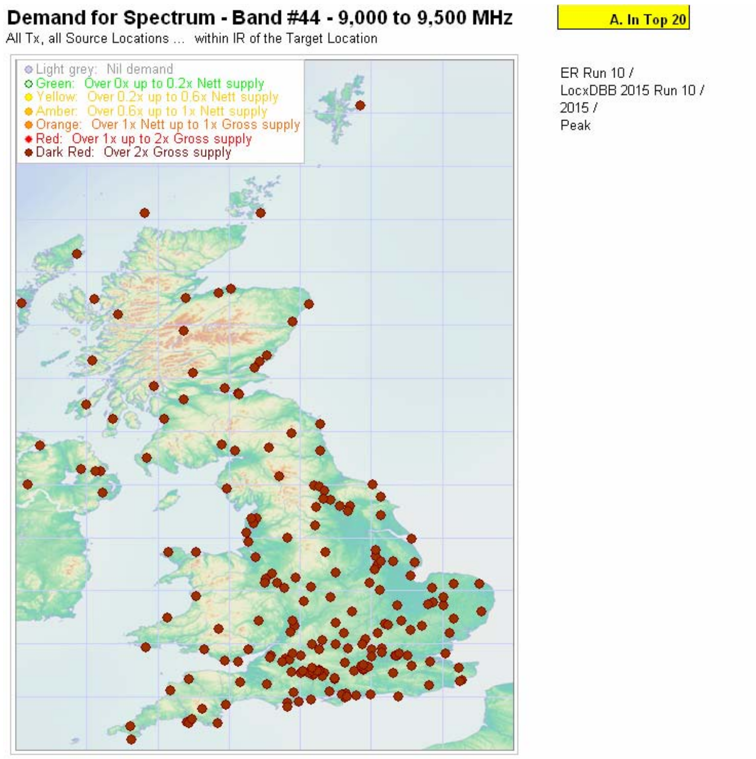
Other opportunistic users in the band, which have not been explicitly included in our modelling for this band, include:

- Some EW calibration to ships
- Cloud collision warning radar
- Met Office wind radars.

It is felt that these systems are either so localised that they are not likely to add to the overall spectrum demand in this band, or do not represent MOD demand for spectrum.

3.17.2 2015 view

Band	Total Demand	MOD Demand, met within Supply	Apparent Spare Spectrum	Unavailable, Shared Spectrum	MOD Demand, in excess of Supply
9,000 to 9,500 MHz	1476 MHz	500. MHz	---	---	976 MHz



This band sees a further increase of 347MHz in forecast demand. The main changes from 2010 are:

- The Tornado Foxhunter AI24 radar will be out of service by 2015
- JSF A-A and A-G radars will be introduced by 2015. These will further increase the spectrum demand in this band, as the bandwidths they can occupy are even greater than the Foxhunter radar.

3.17.3 Band analysis

Geographic issues and potential for geographic sharing

There seems little prospect of sharing spectrum, even on a geographic basis given:

- The level of over-demand within this band
- That much of this over-demand is from ubiquitous transmissions (either airborne or at sea).

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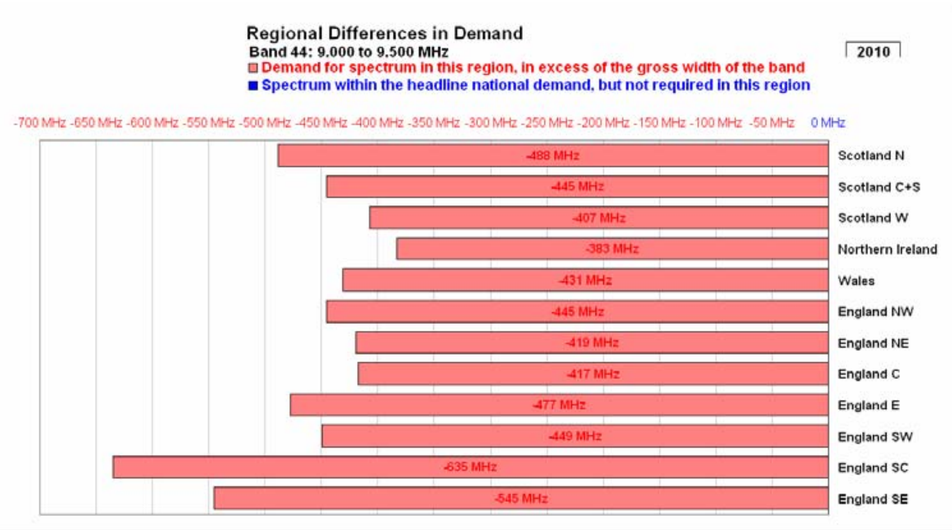


Figure 3-30: Differences in demand: 9000-9500MHz

Potential for spectrum release

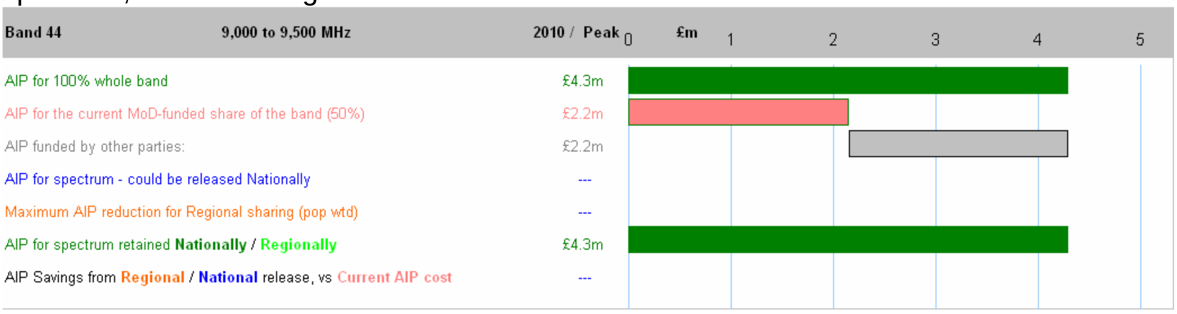
As for Band 42 above, this band represents part of a very busy area of spectrum between 8500MHz – 10000MHz. Looking across that wider band and within this band itself, there seems little prospect of a national release of spectrum in this band.

Other options for reducing spectrum requirement in this band

As noted for Bands 30 and 42 above, we currently assume that surveillance and weapons radars need to be deconflicted using different channels. If, in practice, this deconfliction can be achieved using pulse profiling (or other techniques) to differentiate radar transmissions in the same channel, this will reduce the number of channels needed and therefore reduce the total spectrum demand in this band.

Economic impact of demand

There appears to be no potential for saving AIP costs in this band through release of spectrum, even on a regional basis.



3.17.4 Notes on Cave audit findings

The Cave Audit findings on this band state "…there is insufficient evidence to demonstrate that the total bandwidth is needed. Scope for releasing some of this spectrum should therefore be explored".

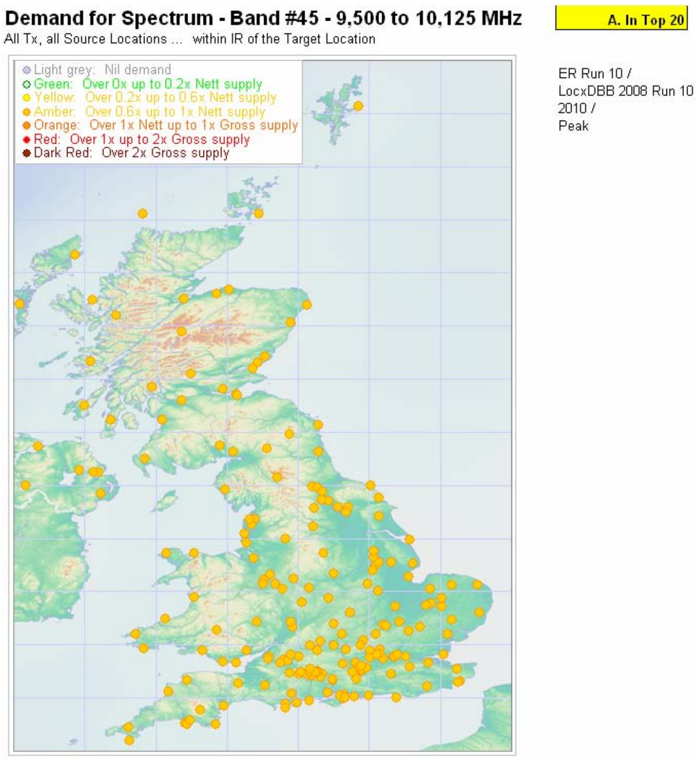
This report's findings show that there is significant over-demand for spectrum in this band from both airborne and ship-based radars, which will be further exacerbated with the introduction of the JSF by 2015, with its wide-band radars. This over-demand is probably shared in practice with the adjacent bands between 8500MHz – 10125MHz, as many systems can operate across this wider range of frequencies.

As such, we see little prospect of releasing or sharing spectrum in this band.

3.18 BAND 45 : 9500MHZ – 10125MHZ

3.18.1 2010 view

Band	Total Demand	MOD Demand, met within Supply	Apparent Spare Spectrum	Unavailable, Shared Spectrum	MOD Demand, in excess of Supply
9,500 to 10,125 MHz	552 MHz	552. MHz	73. MHz	---	---



Overall usage

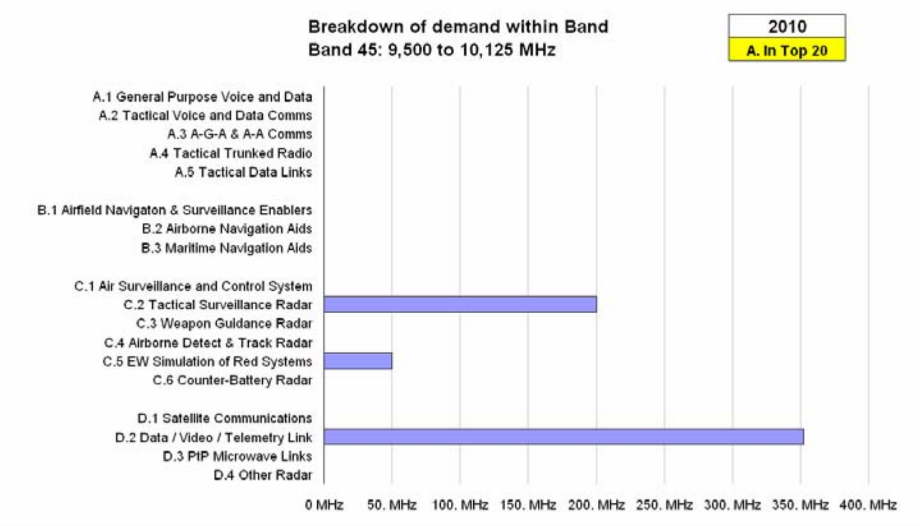


Figure 3-31: Demand for spectrum: 9500-10125MHz

This band shows some spare spectrum at 73MHz.

As noted previously, this band represents part of a very busy area of spectrum between 8500MHz – 10000MHz. Some of the systems currently allocated to Band 44 (9000MHz – 9500MHz) may in fact be capable of operating in this band. This would have the effect of increasing demand beyond the capacity of this band.

Key systems in use

There is significant spectrum demand from:

- ASTOR WBDL uplink (Common Data Link)
- Nimrod and Sea King Mk7 Searchwater radar
  - Some details for these radars were not available at the date of this report, with the potential for subsequent impact on the results for this band.
- Watchkeeper UAV Automatic Take-Off and Landing System
- EW Simulation at Spadeadam
- AMRAAM missile data link
- Meteor missile test and development.

A large proportion of the demand in this band is treated as ubiquitous (either airborne or at sea).

Opportunistic uses of band

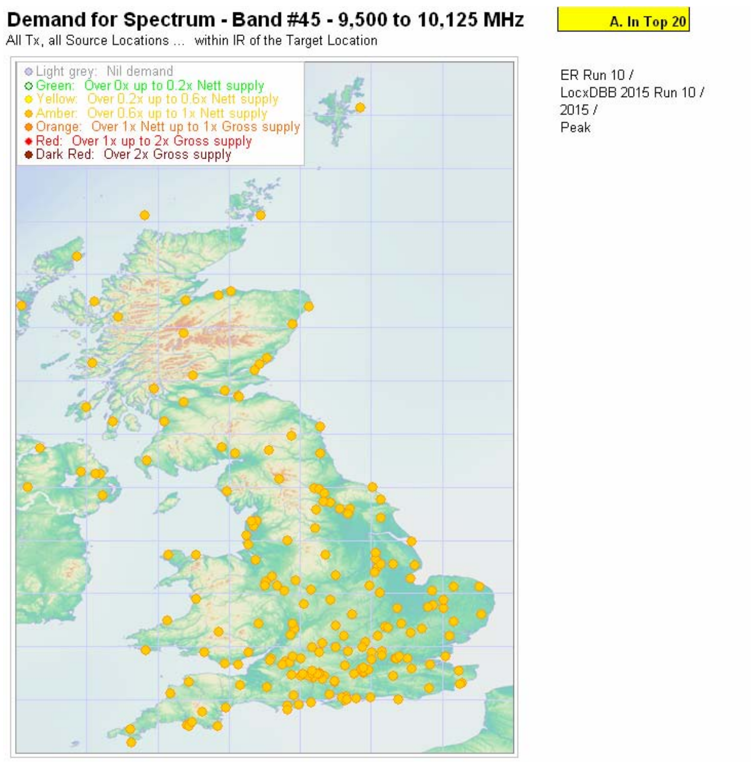
Other opportunistic users in the band, which have not been explicitly included in our modelling for this band, include:

- Some EW calibration to ships
- Some rain radars.

It is felt that these systems are either so localised that they are not likely to add to the overall spectrum demand in this band, or do not represent MOD demand for spectrum.

3.18.2 2015 view

Band	Total Demand	MOD Demand, met within Supply	Apparent Spare Spectrum	Unavailable, Shared Spectrum	MOD Demand, in excess of Supply
9,500 to 10,125 MHz	574 MHz	574. MHz	51. MHz	---	---



This band sees an increase of 22MHz in demand by 2015. The main change from 2010 is:

- The Meteor missile will be deployed operationally by 2015. This will see an increase in the number of channels required, as well as seeing it potentially anywhere in UK airspace.

3.18.3 Band analysis

Geographic issues and potential for geographic sharing

From the maps above, it can be seen that the spectrum demand within this band is spread across the UK, with Northern Ireland as the only obvious region with lower demand in 2010 (but not 2015). This is because much of the transmission in this band is airborne and therefore ubiquitous.[13]

There are therefore limited options for geographical sharing of spectrum above and beyond any spectrum that might be released on a national basis.

[13] Ofcom has already carried out some detailed analysis of the potential for sharing in the context of a spectrum licence award: http://www.ofcom.org.uk/radiocomms/spectrumawards/completedawards/1040award/key/

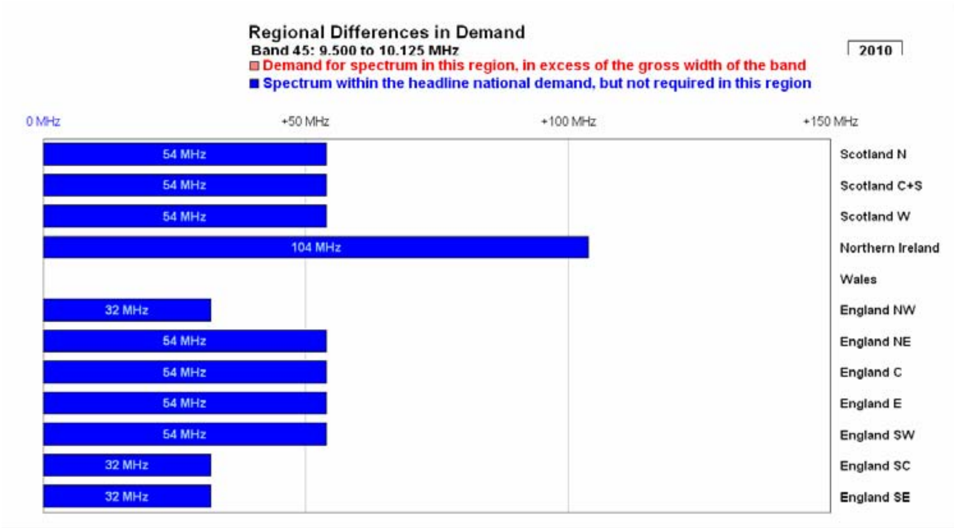


Figure 3-32: Differences in demand: 9500-10125MHz

Potential for spectrum release

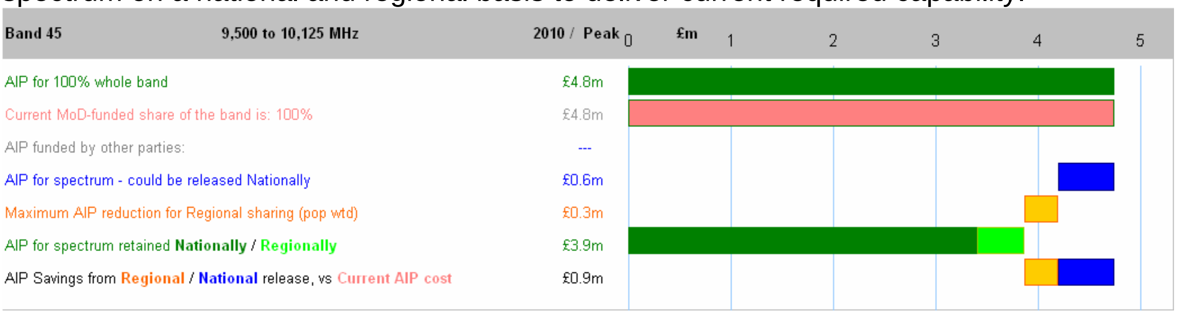
Looking at the total demand above, there would appear to be some prospect for release of some spectrum from within this band. However, as noted for Bands 42 and 44 above, this band represents part of a very busy area of spectrum between 8500MHz – 10000MHz. Looking across that wider band set, there seems little prospect of a national release.

Other options for reducing spectrum requirement in this band

None identified.

Economic impact of demand

There appears to be some small potential for national release of spectrum within this band, with some further opportunities for additional regional releases. The MOD is responsible for 100% of this band, but could nearly £1M p.a., while retaining enough spectrum on a national and regional basis to deliver current required capability.



3.18.4 Notes on Cave audit findings

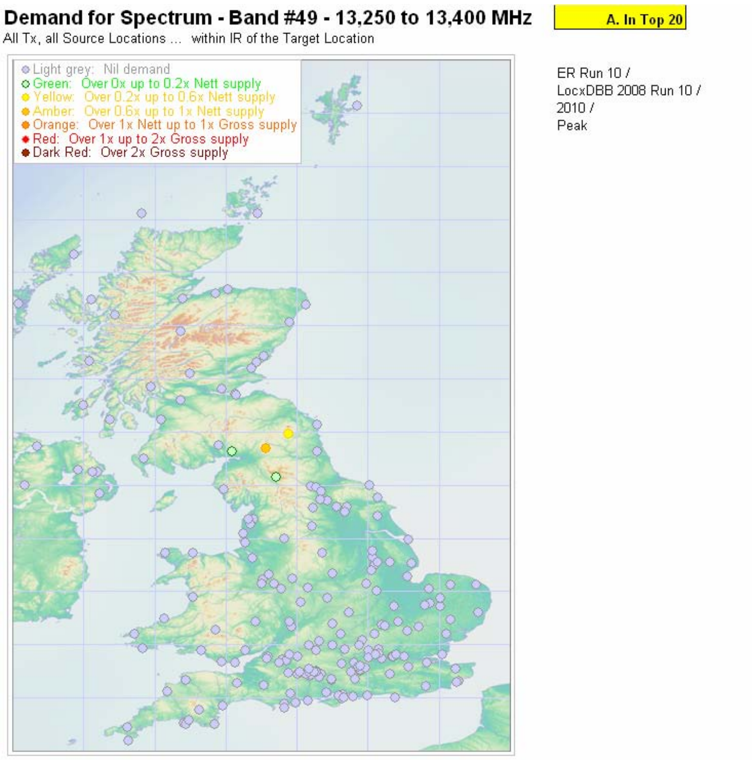
The Cave Audit reports on 8500-10500MHz (excluding 9000-9500MHz) as a single band. This report looks at separate sub-bands within this.

Overall, the Cave Audit suggests that there is good scope for releasing or sharing spectrum in this band. This report finds that there is significant demand from MOD systems above, both within this band and across the wider 8500MHz – 10125MHz.

3.19 BAND 49 : 13250MHZ – 13400MHZ

3.19.1 2010 view

Band	Total Demand	MOD Demand, met within Supply	Apparent Spare Spectrum	Unavailable, Shared Spectrum	MOD Demand, in excess of Supply
13,250 to 13,400 MHz	91 MHz	91. MHz	59. MHz	---	---



Overall usage

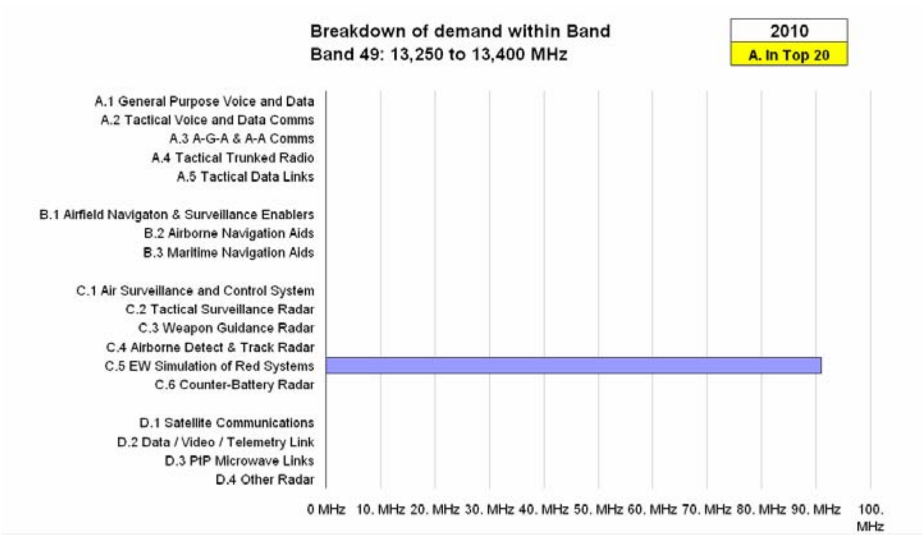


Figure 3-33: Demand for spectrum: 13250-13400MHz

This band shows a significant amount of spare spectrum at 59MHz.

Key systems in use

The only demand identified in this band is for various EW simulation systems at Spadeadam.

Opportunistic uses of band

None identified.

3.19.2 2015 view

Band	Total Demand	MOD Demand, met within Supply	Apparent Spare Spectrum	Unavailable, Shared Spectrum	MOD Demand, in excess of Supply
13,250 to 13,400 MHz	91 MHz	91. MHz	59. MHz	---	---

No significant changes in systems or spectrum demand are foreseen between 2010 and 2015.

3.19.3 Band analysis

Geographic issues and potential for geographic sharing

As can be seen from the map above, the demand for spectrum in this band is highly localised at Spadeadam. Therefore there are excellent prospects for geographical release or sharing of spectrum in this band.

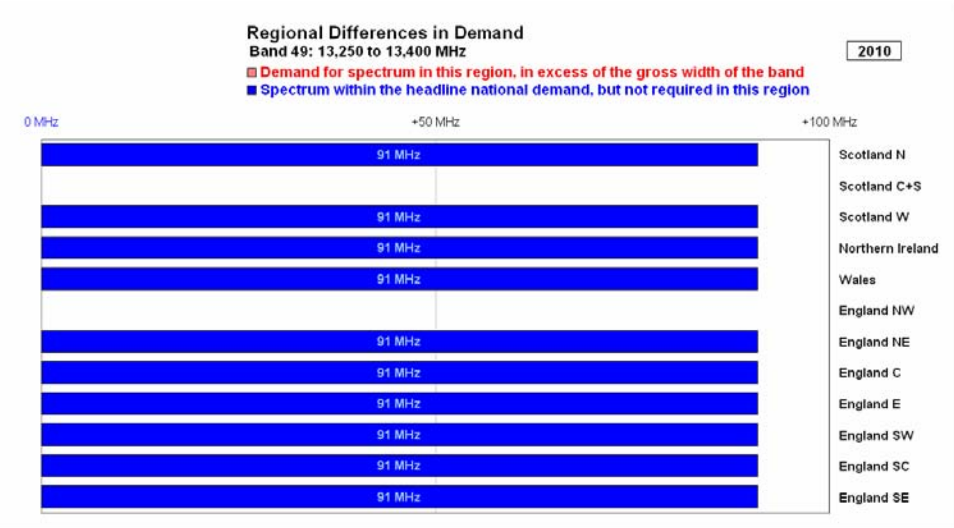


Figure 3-34: Differences in demand: 13250-13400MHz

Potential for spectrum release

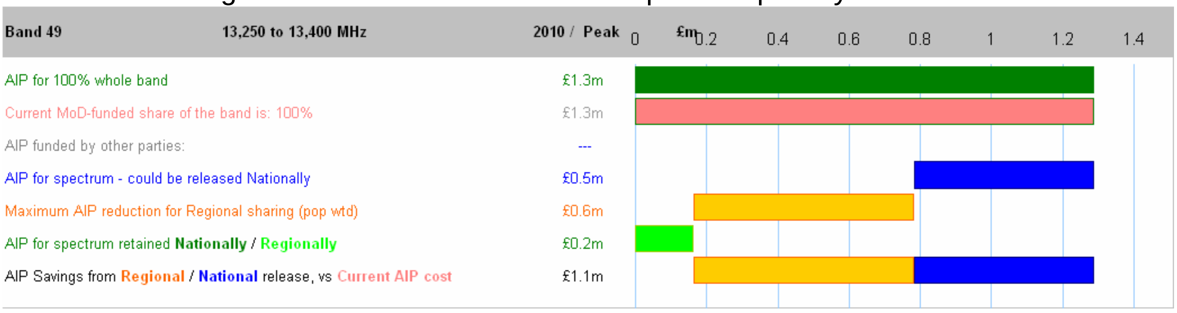
The use of spectrum in this band at Spadeadam may make a national release of spectrum difficult unless the exact use of frequencies there can be limited. If this can be achieved, then there is a good prospect of releasing spectrum in this band on a national basis.

Other options for reducing spectrum requirement in this band

A more detailed study of the transmission requirements at Spadeadam may lead to a further reduction in the actual spectrum demand in this band. If different systems can share the same frequencies on a temporal basis there, then total demand can be reduced. This would then improve the prospects of a national release of spectrum in this band.

Economic impact of demand

There appears to be good potential for national release of spectrum within this band, with significant further opportunities for additional regional releases. The MOD is responsible for 100% of this band, but could save over £1M p.a., while retaining enough spectrum on a national and regional basis to deliver current required capability.



3.19.4 Notes on Cave audit findings

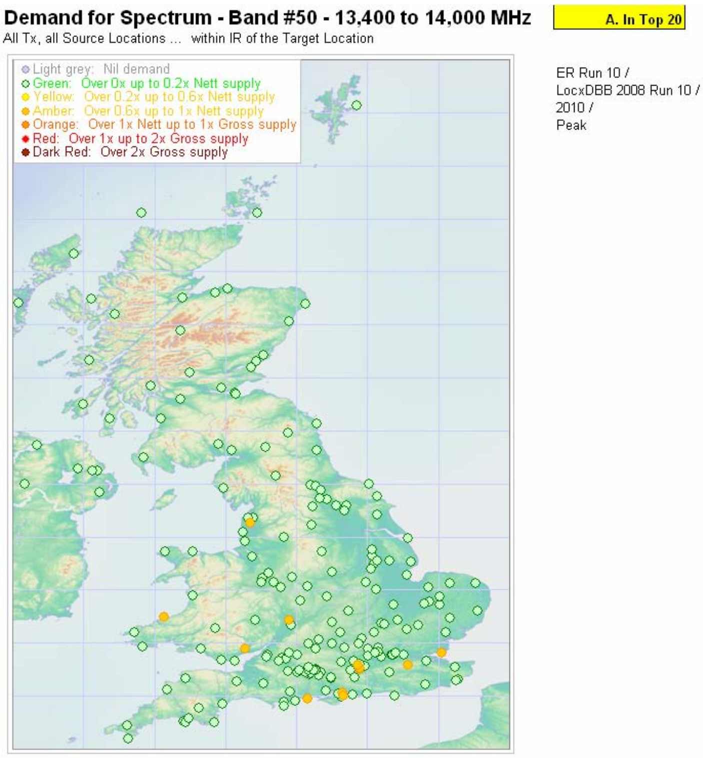
The Cave Audit reports on 13.25-14.00GHz as a single band. This report looks at separate sub-bands within this.

Overall, this report's findings are in agreement with the Cave Audit in seeing good potential for release or sharing of spectrum in this band.

3.20 BAND 50 : 13400MHZ – 14000MHZ

3.20.1 2010 view

Band	Total Demand	MOD Demand, met within Supply	Apparent Spare Spectrum	Unavailable, Shared Spectrum	MOD Demand, in excess of Supply
13,400 to 14,000 MHz	282 MHz	282. MHz	18. MHz	300. MHz	---



Overall usage

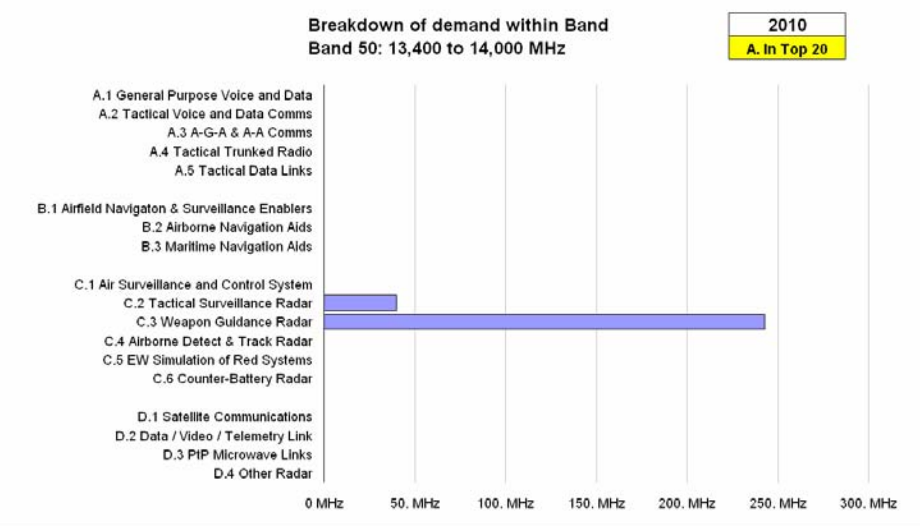


Figure 3-35: Demand for spectrum: 13400-14000MHz

This band shows a small amount of spare spectrum at 18MHz.

Key systems in use

There is significant spectrum demand in this band from:

- Meteor missile radar seeker
  - This is only testing currently in UK, it is not yet deployed
- Rapier Dagger radar
- There is also a naval T909 radar in this band, but without significant spectrum demand.

Opportunistic uses of band

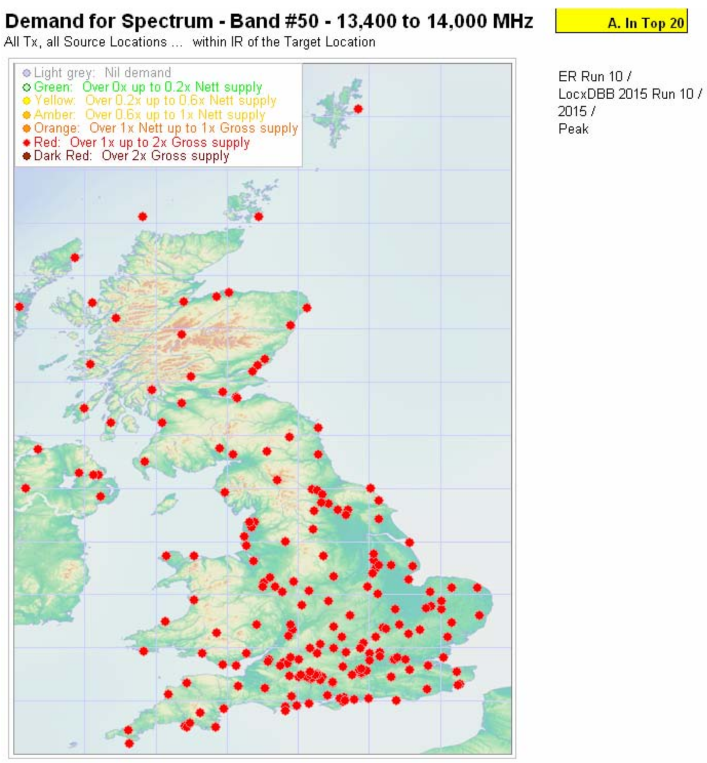
Other opportunistic users in the band, which have not been explicitly included in our modelling for this band, include:

- Some EW calibration to ships.

It is felt that these systems are so localised that they are not likely to add to the overall spectrum demand in this band.

3.20.2 2015 view

Band	Total Demand	MOD Demand, met within Supply	Apparent Spare Spectrum	Unavailable, Shared Spectrum	MOD Demand, in excess of Supply
13,400 to 14,000 MHz	1000 MHz	600. MHz	---	---	400. MHz



This band sees a massive increase in demand of 718MHz by 2015. The main changes from 2010 are:

- The Meteor missile will be deployed operationally by 2015. This will see an increase in the number of channels required, as well as seeing it potentially anywhere in UK airspace.
  - Some details for these radars were not available at the date of this report, with the potential for subsequent impact on the results for this band.
- The T909 naval radar goes out of service by 2015 (it is only on T42 destroyers), but this only sees a small reduction in spectrum demand in this band.

3.20.3 Band analysis

Geographic issues and potential for geographic sharing

From the maps above, it can be seen that in 2010, much of the spectrum demand is localised and raises a good prospect of geographical sharing of spectrum. However, in 2015, this picture changes to show significant over-demand throughout the UK. This is due to the Meteor missile coming into operation, with the prospect of use or training anywhere in UK airspace.

- It is unlikely that any geographic sharing can be achieved in this band without further study into the likely use of the Meteor missile in the UK once it is deployed operationally.

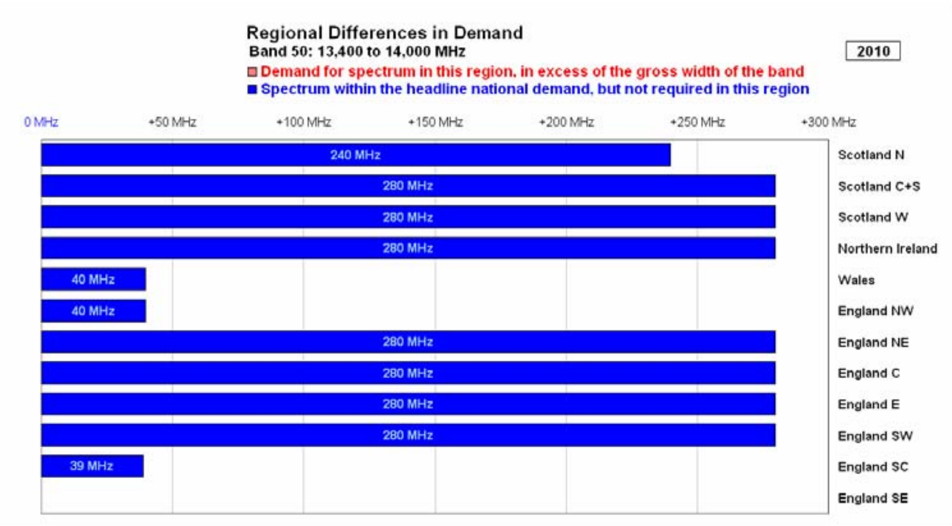


Figure 3-36: Differences in demand: 13400-14000MHz

Potential for spectrum release

As for geographic sharing, it is unlikely that any national release of spectrum can be achieved in this band without further study into the likely use of the Meteor missile in the UK once it is deployed operationally.

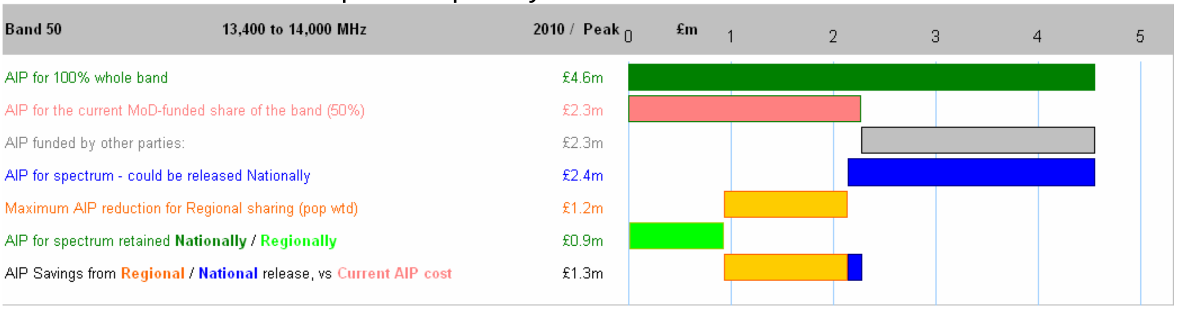
Other options for reducing spectrum requirement in this band

None identified.

Economic impact of demand

There appears to be significant potential for national release of spectrum within this band, with some further opportunities for additional regional releases.

The MOD currently pays 50% of the AIP cost for this whole band (£4.6M p.a.), but could save a further £1.3M p.a., while retaining enough spectrum on a national and regional basis to deliver current required capability.



3.20.4 Notes on Cave audit findings

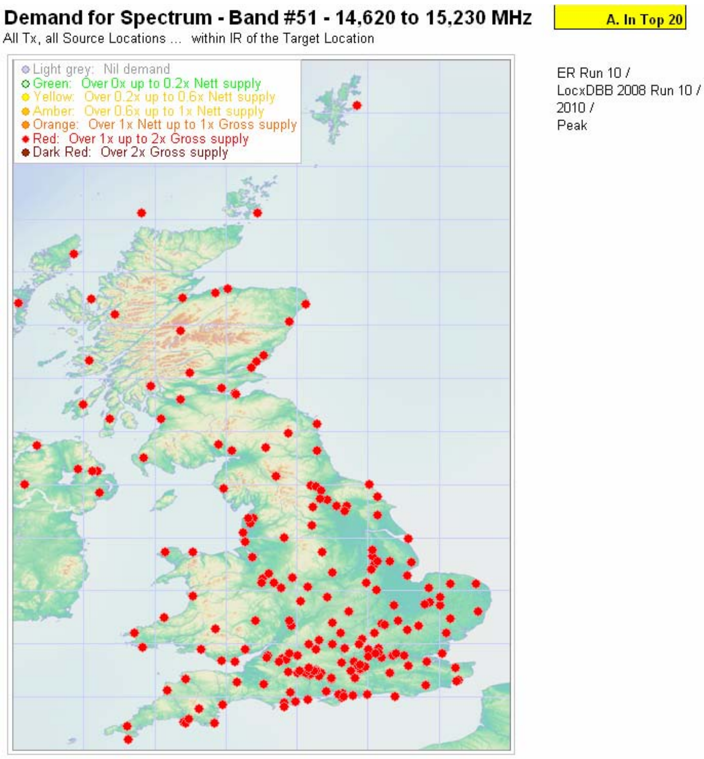
The Cave Audit reports on 13.25-14.00GHz as a single band. This report looks at separate sub-bands within this.

The Cave Audit findings suggest a good potential for release or sharing of spectrum in this band. This report does not see much potential for the sharing of spectrum within this specific band, particularly with the operational deployment of the Meteor missile in the future.

3.21 BAND 51 : 14620MHZ – 15230MHZ

3.21.1 2010 view

Band	Total Demand	MOD Demand, met within Supply	Apparent Spare Spectrum	Unavailable, Shared Spectrum	MOD Demand, in excess of Supply
14,620 to 15,230 MHz	981 MHz	610. MHz	---	---	371.4 MHz



Overall usage

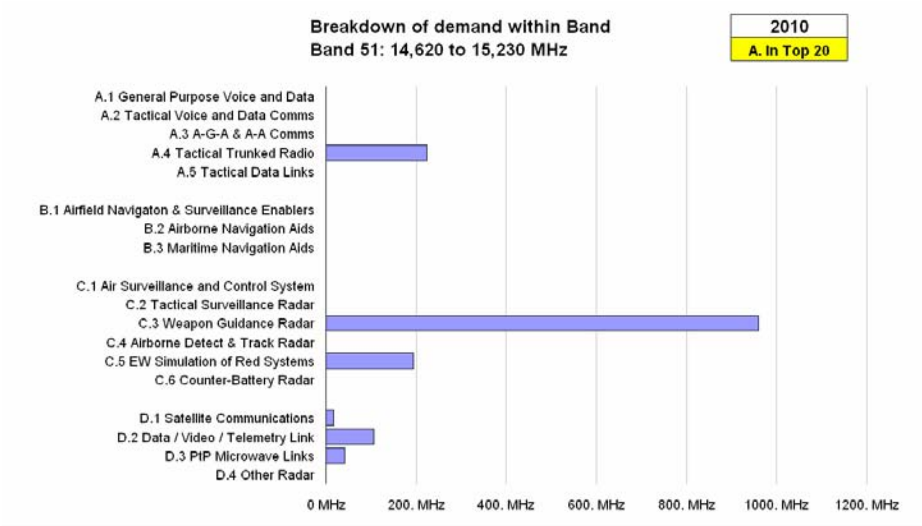


Figure 3-37: Demand for spectrum: 14620-15230MHz

This band shows a significant amount of over-demand for this band.

Key systems in use

The majority of demand in this band is due to our treatment of Phalanx search and track radars.

- Some details for these radars were not available at the date of this report, with the potential for subsequent impact on the results for this band.
  - We treat this system as Ku-band (12GHz – 18GHz), so it falls into this band by default for modelling purposes.
- A large proportion of this Phalanx demand is treated as ubiquitous (i.e. on ships at sea).

Other large demands include:

- Cormorant – There is just under 100MHz of paired spectrum in this band used for Cormorant trunked radio (14621MHz – 14718MHz paired with 15041MHz – 15138MHz)
- EW simulation at Spadeadam and other minor EW simulation sites.

Opportunistic uses of band

Other opportunistic users in the band, which have not been explicitly included in our modelling for this band, include:

- Some EW calibration to ships.

It is felt that these systems are so localised that they are not likely to add to the overall spectrum demand in this band.

3.21.2 2015 view

Band	Total Demand	MOD Demand, met within Supply	Apparent Spare Spectrum	Unavailable, Shared Spectrum	MOD Demand, in excess of Supply
14,620 to 15,230 MHz	981 MHz	610. MHz	---	---	371.4 MHz

No significant changes in systems or spectrum demand are foreseen between 2010 and 2015.

3.21.3 Band analysis

Geographic issues and potential for geographic sharing

Since a large proportion of the Phalanx radar spectrum demand is treated as ubiquitous, the spectrum demand for Cormorant and EW simulation is treated as additional further demand.

However, in practice, the Phalanx radar will only transmit at sea, allowing for significant possibilities for geographical sharing with land-based systems. This could significantly reduce the total spectrum demand within the band.

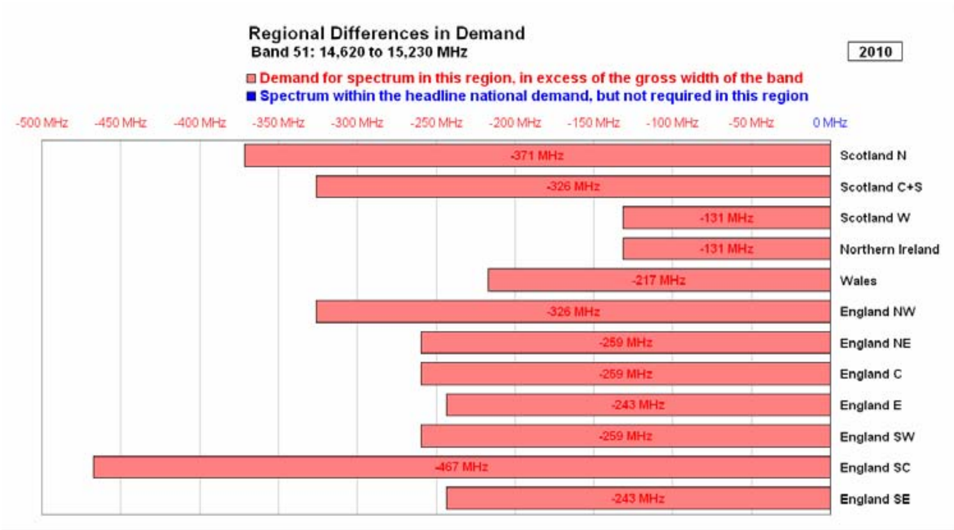


Figure 3-38: Difference in demand: 14620-15230MHz

Potential for spectrum release

Some details for radars were not available at the date of this report, with the potential for subsequent impact on the results for this band. However, as this band already appears over-subscribed, it seems unlikely that changes in the technical parameters for some systems will change that overall picture.

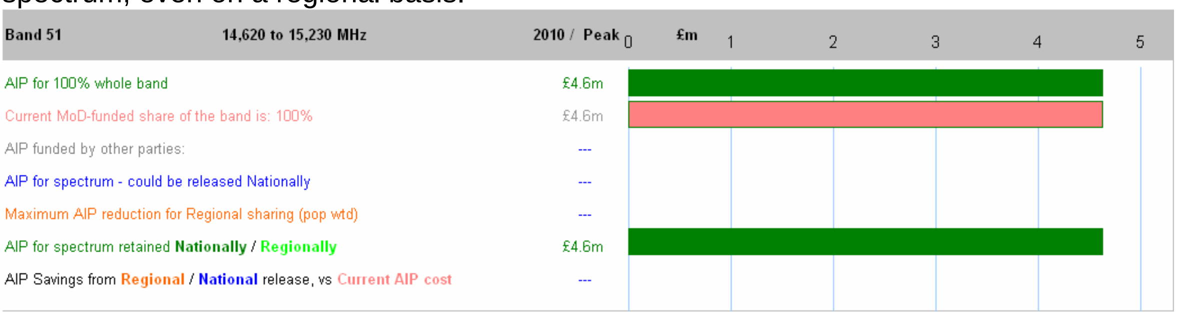
Based on the current data, it seems that there is little prospect of a national release of spectrum in this band.

Other options for reducing spectrum requirement in this band

As noted above, the Phalanx radar spectrum demand is treated as additive to the spectrum demand for Cormorant and EW simulation. If this can be shown to be limited to transmissions at sea with minimal impact on land-based transmissions in this band (due, for example, to its limited operating range at this frequency), then overall spectrum demand in this band can be reduced further.

Economic impact of demand

There appears to be no potential for saving AIP costs in this band through release of spectrum, even on a regional basis.



3.21.4 Notes on Cave audit findings

The Cave Audit does not explicitly report on this band.

3.22 NOTES ON BAND RESULTS

Considering the results above there are a number of key lessons:

- There appears to be considerable potential for increased geographic sharing in many bands
- There are a number of cases where a band has excess demand either in 2010 or 2015, whilst an alternative band has excess supply. Some rebanding of existing equipment could deliver benefits here
- There are a number of cases where equipment is operating in 'high AIP' bands, whereas it could equally operate elsewhere. Again, rebanding could deliver benefits in the form of financial savings

4. 2027 – DEMAND FOR SPECTRUM

4.1 INTRODUCTION

To estimate Defence Spectrum Demand in 2008 and 2015 we have constructed a model which considers the cumulative demand created by the systems associated with the military capability based at a large number of sites across UK, together with UK waters and airspace.

Whilst we can make good data assumptions about today's systems, and in the majority of cases those in-service in 2015, there is considerable uncertainty about the 2027 epoch. Whilst at present much of the inventory is in-service or at an advanced stage of development, a significant proportion is not. Therefore detailed modelling along the lines of what we have done for 2008 and 2015 is inappropriate for understanding demand over this timeframe. In the sections below we consider the changes that could lead to modified spectrum demand, and the effect that they are likely to have by application, and then by frequency band.

The following sections cover:

- Strategic trends, which are used to shape MOD future Defence requirements
- The Defence Plan and future Capability development
- Implications for the Services (AIR, LAND, FLEET)
- Implications for the Equipment Plan
- Technological changes expected over the timeframe to 2027.

4.2 STRATEGIC TRENDS

The Development Concepts and Doctrine Centre (DCDC)[14] produces "Global Strategic Trends". This is part of the UK MOD Strategic context process from which the department derives guidance about strategic challenges and opportunities, which is used to shape the UK's future Defence requirements.

The Strategic Trends summary examines trends in:

- Conflict and confrontation
- Conflict environments
- Organisation and resources
- Conflict actors and human impacts
- Attitudes, laws and norms in conflict.

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[14] ***Strategic Trends*** is an independent view of the future produced by the Development, Concepts and Doctrine Centre (DCDC), a Directorate General within the UK's Ministry of Defence (MOD). It is a source document for the development of UK Defence Policy. http://www.dcdc-strategictrends.org.uk/home.aspx

Rather than summarise the Strategic Trends analysis here, we refer the reader to the source referenced above. However, we have analysed the trends for their likely effect on spectrum, as detailed below.

The Impact on Spectrum

From the perspective of this Study we see the following issues arising from the above:

- The need to train for a wide range of operations ranging from large scale intervention against a well equipped enemy through the conduct of what would traditionally be termed “war fighting” operations, through complex and dangerous stability operations (of the sort currently being conducted in Afghanistan and Iraq), to peace-keeping operations, and small scale focussed interventions using precision strike.
- The increasing emphasis on land as the supported environment, but with effects being delivered from the sea and air, increasing the importance of littoral operations and close air support.
- An increasing emphasis on conducting operations in an urban environment and among a civilian population which poses challenges for both ISTAR and communications systems.
- The continuing emphasis on Network Enabled Capability (NEC). From this Study’s perspective we are less concerned with the passage of data over high capacity links such as Skynet or Falcon, or whether there is sufficient capacity in some systems (e.g. Bowman HCDR) to meet expectations, or how information is handled to inform decision making within a head-quarters. Nor do we believe that there is significant spectrum demand associated with training with the relevant effectors such as precision weapons. However we consider that there are peacetime spectrum issues associated with the provision of imagery from overhead sensors which requires suitable wide bandwidth down-links to be provided.

4.3 THE DEFENCE PLAN AND CAPABILITY DEVELOPMENT

The Defence Plan 2008[15] outlines four areas for developing future capabilities:

- Implement force structure changes through, in particular, the Future Navy Plan, rebalancing of the Army in line with the Future Army Structure and the Royal Air Force's Transformation programme
- Enhance command, control and communications, in particular through Network Enabled Capability
- Integrate new and enhanced military equipment across all Defence Lines of Development
- Exploit technology using the latest advances to improve Defence Capabilities.

4.3.1 Military capability programmes

The following major military capability programmes have been identified:

- UK Military Flying Training System – a programme to replace the present flying training arrangements for the Royal Air Force, Fleet Air Arm and Army Air Corps with a single tri-Service military flying training system
- Nuclear Deterrence Capability – a programme to sustain a credible nuclear deterrent capability beyond the life of the current system
- Joint Medium Weight Capability – a task-organized joint force designed to achieve an improved range of effects more rapidly in expeditionary operations
- Helicopters' Capability – improvement projects to ensure continuity of capability of helicopter fleets
- Combat Identification – a programme to improve situational awareness at sea, on land and in the air, which also ensures interoperability with US forces
- Carrier Strike– a Joint Force capability comprising Joint Combat Aircraft, Future Carrier, Maritime Airborne Surveillance and Control and other enabling projects
- Future Strategic Tanker Aircraft – replacing the air to air refuelling and some elements of air transport capability currently provided by RAF VC10s and TriStars
- Urgent Operational Requirements – delivery of improvements to the process for procuring equipment that is urgently needed for specific operations
- Counter Improvised Explosive Device (C-IED) Capability - a programme to drive coherence across the range of C-IED capabilities in order to deliver freedom of manoeuvre to operational commanders
- Test and Evaluation (T&E) – a programme to drive change across the range of the Department's T&E capability in order to improve coherence and provide best value for Defence

[15] Defence Plan Presented to Parliament by The Secretary of State for Defence, June 2008. http://www.official-documents.gov.uk/document/cm73/7385/7385.pdf

- Future Core Network - a programme to introduce a unified strategic pan-Defence communications network supporting both operations and business functions; a key enabler in delivering a Global Information Infrastructure and NEC.

4.3.2 Network Enabled Capability

“Network Enabled Capability (NEC) is worthy of special mention because, as noted in the Defence Plan:

(NEC…) will deliver benefit by enabling decision superiority across both the battle space and the business space. It is considerably more diverse than equipment and improved technical solutions; ultimately it is cultural with implications for doctrine, organisation, structure, training, tactics and procedures. It will enable the situational awareness and the command and control required to plan, execute and co-ordinate precise and effective actions conducted as part of a comprehensive approach to operations, by providing the required degree of national, international and cross-departmental interoperability at all levels of command.”

NEC itself does not highlight specific radio communication technologies, although it will certainly be a key driver in the use of radio spectrum.

4.4 THE SERVICES

The implications for the services presented below are derived from the Strategic Trends and Defence Plan documents referenced above, together with the Future Land Operational Context[16].

4.4.1 The Naval Component

Naval radars are one of the largest generators of spectrum demand within our model. They combine high power and large bandwidth to achieve the desired performance level. Furthermore the inherently flexible nature of naval forces which, whilst operating primarily in two main areas can operate anywhere in UK waters, means that we have had to treat them as virtually ubiquitous, with little opportunity for frequency reuse through geographical separation. However, with the introduction of new techniques and technologies as discussed in Section 4.8 this may no longer be necessary.

Doctrinal Perspective

From a doctrinal perspective the most significant factor is likely to be the increased emphasis on naval support to the land environment with the emphasis on littoral operations. This will involve training for amphibious operations, naval fires, naval air defence capabilities reaching over land etc. All this means that naval exercises will increasingly take place relatively close to land, and will increasingly have to take into account the potential for interference with land usage of the spectrum.

Organisational Perspective

The most critical factor in the maritime environment is not so much the introduction of new radars, but the difficulty in making assumptions about frequency reuse, and this primarily rests on assumptions about the "worst case" for spectrum demand, ie the maximum number of ships that can be assembled in peace-time to form task groups for exercises in UK waters. For example as the total number of AAW destroyers goes down if Type 42s are not replaced on a one for one basis, then there will be limits on how many Type 45s HQ Fleet can expect to deploy for exercises in UK waters.

We would however caution against "micro-managing" the naval radar bands 20 years hence as allowance will have to be made for non-UK ships exercising in UK waters in combined exercises, and it is almost impossible to predict the radar characteristics of all the possible permutations of overseas ships and associated radars that such exercises might produce. It may be that some level of 'unprotected' sharing is possible, with applications using those bands having to avoid interfering with Naval use offshore.

Equipment Perspective

The maritime environment is characterised by very long lead times and, except for the Future Surface Combatant as a replacement for Type 22 (and possibly Type 23) frigates most major platform characteristics are already well known. Even mid-life updates e.g. replacement of various in-service radars by Medium Range Radar (MRR) are already relatively well defined, and only likely to make small changes to the demand picture.

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16 http://www.mod.uk/DefenceInternet/MicroSite/DCDC/OurPublications/Concepts/TheFutureLandOperationalConcept2008.htm

4.4.2 The Land Component

Doctrinal Perspective

The most significant factors in the land environment are increasing emphasis on urban operations and acceptance of IEDs as enduring threats. This poses 3 related challenges:

Communications: Military VHF works poorly in urban environments. The very high density of forces in built up areas, coupled with poor visibility poses command and control challenges. To improve this there will be a need to pass voice, data and imagery. Although there are challenges with designing and introducing a militarised system, Defence will wish to exploit such technology, using such techniques as mesh-networks.

Urban ISTAR: Urban areas pose particular ISTAR challenges as forces need information about what is inside buildings, up alleys etc. High level systems such as Watchkeeper or ASTOR are of limited use, leading to a need for alternative ISTAR designed for this environment. This is likely to be met by a variety of systems including micro-UAVs, unmanned ground vehicles, etc able to transmit video hundreds of metres. Defence may also exploit the spectrum to provide new sensors (e.g. through wall X ray). These are all likely to be relatively low power, with other assets acting as relays where needed.

Counter IED: The IED threat is seen as enduring with an ongoing need for electronic counter-measures (ECM). Where wireless devices are used as triggers, adversaries normally use commercial systems such as mobile phones. Defence will increasingly wish to reflect IEDs and ECM in training and the fact that the threat will exist in civil bands means that the Services will not be able to disrupt them routinely whilst training in UK and will instead rely on some form of emulation. Need for access to spectrum in the UK for C-IED operations is dealt with separately, e.g. the Civil Contingencies arrangements.

Organisational Perspective

Within the Land environment the most significant factor is the planned move of a manoeuvre brigade from Germany to the proposed West Midland super-garrison[17]. However overall we do not believe that this will impact significantly on spectrum demand. There will be a requirement for in-barracks Bowman testing and training but this can be conducted at low power levels, and the proposed locations are outside the interference range from major training areas such as Salisbury Plain or Sennybridge. A similar argument applies to in-barracks testing of radar systems. The critical factor in spectrum use (particularly Bowman and artillery locating radars) in the land environment within UK is not the number of units or systems, but training area availability which restricts the number of systems that can be deployed at any given moment. – this will provide some limit to use of wireless systems.

Equipment Perspective

Land Forces are about to benefit from considerable investment in bearers such as Bowman, Falcon and Cormorant. These will continue in service for many years, albeit with technical insertions and upgrades. In general we believe that the enduring demands for high quality voice on in manoeuvre units will continue to be met by VHF, although recent improvements in HF may mean that this finds increased favour. At formation level, UHF relay with high capacity for voice / data will continue to be the primary bearer.

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[17] Appendix I – Future Locations Assumptions

4.4.3 The Air Component

Doctrinal Perspective

Recent changes in Defence structures and outputs have placed increasing emphasis on air support to the land environment as an element of joint fires. This suggests an increasing emphasis on training for this role, both on weapons ranges and training areas.

Organisational Perspective

Although there are planned changes to the RAF's basing strategy[18] we do not believe that the closure of a small number of airfields will have a significant impact on overall spectrum demand. In the model we are not concerned with locations of aircraft squadrons, or exactly how many of each type of aircraft are in service. Given their inherent speed and flexibility we have treated aircraft as ubiquitous, and have made assumptions about the maximum number that might be airborne in UK airspace for a major NATO Red Flag exercise as our "worst case", and have assumed a similar size of exercise in 2027 as in 2008.

We note the current debate over the impact of off-shore wind-farms on ASACS performance. Whilst research is being conducted to look at mitigation, there may be a requirement to increase the number of radar sites, using in-fill, to reduce dead-spots behind wind-farms with a consequent increase in channel usage and spectrum demand.

Equipment Perspective

The most significant technical trend in the air environment is the increased proportion of fast jets that will be equipped with highly capable radars.

- Harrier GR9, which is not equipped with a radar, is being replaced by F-35 Joint Strike Fighter. This is equipped with a highly capable multi-mode radar, which in some modes uses very high bandwidth and power.
- We assume that the Typhoon radar will be updated in due course. If its use is primarily an air to air sensor then the net demand may remain broadly constant. However in view of the increasing emphasis on the aircraft's air to ground role it may be provided with something akin to that found on the F35.

All things being equal therefore we would envisage an increase in the use of airborne radars emitting over and down to UK. In practice, environmental concerns and air space constraints may limit the number of aircraft that can be deployed for any such exercise so that the scale of effort is more likely to represent the style of operations in Afghanistan in 2008 rather than the "shock and awe" in Iraq in 2003. However even single figure quantities of F-35 using their radar will represent a significant increase in spectrum demand compared to current practice.

The Station Keeping radar fitted to C-130 is virtually the sole driver of spectrum demand in the 3.4-3.6 GHz band. There may be opportunities to migrate out of this band as the aircraft are replaced, and the amount of spectrum associated with this capability is dependent on assumptions on scales of airborne exercises within UK.

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[18] Appendix I – Future Locations Assumptions

ISTAR – Implications for Air. The doctrinal emphasis on ISTAR, together with the experience of current operations, is likely to lead to this broad capability being used more widely in UK based training.

From the Study's perspective we believe that the most significant factor will be an increased use of UAVs on operations, and hence in UK based training.

Whilst Hermes 450 might be seen as filling an ongoing capability requirement previously occupied by Phoenix and to be filled by Watchkeeper in due course, we believe that the capability met by UORs such as Desert Hawk and Reaper is almost certain to be taken into core in due course. DABINETT calls for a deep and persistent ISTAR capability which we assume will be filled by a UAV, and it is assumed that the Future Combat Air Capability will include a highly advanced Unmanned Combat Airborne Vehicle (UCAV).

At the moment almost all UK's UAV capability is deployed on operations having been procured as UORs. There appears to be considerable uncertainty within Defence about how UAVs will be organised, based and train within UK in the longer term. In particular there are no firm policy assumptions about how UAVs will operate UK airspace in terms of control or geography.

However we believe that commanders training their forces will insist on UAV capability being represented on sea, land, air, and joint exercises in UK and the littoral. This capability might be represented by either UAVs or manned aircraft surrogates, but in either case there will be a requirement to provide the spectrum for radar sensors and video downlinks. Hence we see an increasing demand.

4.4.4 UK based counter-terrorism operations

We assume that the very highest priority will be placed on UK based counter-terrorist operations, but we do not believe that this will have a significant impact on spectrum demand.

Explosive Ordnance Disposal (EOD) operations are likely to likely to involve ECM techniques to ensure the safety of the operators by allowing them to operate within a safe "electronic bubble". However this will be relatively localised, and any disruption to civilian or military systems within the vicinity will be acceptable for the duration of the operations.

Special forces operations will be provided with a range of specialist surveillance and communications assets for counter-terrorism operations, but their overall spectrum demand will be low within the wider Defence context, and they can be guaranteed availability when required at the expense of other Defence users through normal spectrum management techniques.

4.5 THE EQUIPMENT PLAN

The MOD Equipment Plan provides a partial picture of what is likely to be in service in 2027, particularly major programmes. However it is sometimes unclear how a major capability requirement will be met, and in many areas the EP does not look beyond 10 years. Also MOD is wrestling with divergence between the EP and Urgent Operational Requirements (UORs). We believe that the EP will be amended with operational lessons, taking UORs into core, or reflecting new capabilities (e.g. UAVs provided through UORs).

CATEGORY A PROJECTS			
Name	Project Description	Main Gate	Study Assumptions
APP	Air Platform Protection		Primarily IR threat, might include RF jammer. Assume that in UK jamming would only be used at Spadeadam against locally generated threats. In our model this is accounted for in the Spadeadam's DBB, (DA4)
FMCMC P900117900	Future Mine Countermeasure (Maritime) - enabling effect mainly via unmanned tech's through mix of Portable, Organic (FSC C1/2) and Dedicated (FSC C3). Programme transferred FBG IPT to SC IPT (was MPH & Frigates) wef Apr 08.	2017	We have ignored this. Whilst this may possibly involve increased use of command links etc, we believe these will be relatively small compared to wider RN systems.
FPALS P900260000	Future Precision Approach & Landing Sysytem being considered in NATO; includes ground and air platform equipment. Ground equip't element tranferred to JMATS.	2020	We have assumed that spectrum use/demand will be similar to in-service systems
FCAC - DPOC P900050200	Renamed FCAC (Future Combat Air Capability). Next generation air platforms (including unmanned combat air vehicles), air launched missiles and networking of platforms, sensors and delivery systems.	2015	Assume in service by 2027. Given concepts of networked UCAVs there may well be significant increase in data link demands.
Future Surface Combatant P900005700	FSC is a key part of the strategy replacing the current capabilities.	2011	Assume in-service by 2027 to replace T22 (and possibly T23). Assume fundamental radar characteristics as for T23.
Network Enabled Air Defence and Surveillance P9002930	Provision of weapon platforms and GBAD C4I to replace BriC	2010	Given the early stage we have assumed current Rapier radar characteristics, and that C4I system will use planned bearers.
CATEGORY B PROJECTS			
MIDAS P900301700	Successor Integrated Defensive Aid Suite for T23	2012	We have assumed no jamming in close littoral waters
SEAD	SEAD capability on Typhoon	2013	We assume this will only be used at Spadeadam, and so is in the latter's spectrum demand.

Figure 4-1: Equipment programme items affecting 2027

4.6 DEFENCE TECHNOLOGY PLAN

The Defence Technology Plan[19] identifies three areas for which road maps are presented as follows:

- Advanced Electronic and Optical Materials
  Harnessing new developments in electro-optic materials. Military advantage through emerging electronic / optical device technologies
- Emerging Quantum Technologies
  Military applications of quantum technology. Game changing quantum technology
- Micro and Nano-technologies
  Game changing micro and nano technologies. Military advantage through application of MNT.

4.7 COMMUNICATIONS TRENDS TO 2025

4.7.1 Research and Development Programmes

There are a number of research programmes being carried out, some led by DTIC (formerly RAO) and some by IPTs. Key programmes likely to have a significant effect are:

- NEC for Close Combat (NEC4CC)
- Future Dismounted Close Combat (FDCC)
- Future Integrated Soldier Technology (FIST)
- Enabling Secure Information Infrastructure (ESII)
- Bowman developments.

These are covered in outline below, with additional detail in Appendix F.

[19] The Defence Technology Plan is under development at the time of writing this report.

NEC for Close Combat

The NEC4CC programme has shown that enhancements in the communications network will deliver benefit to Close Combat in the key areas of:

- Own-force situational awareness
- The ability to self synchronise
- The decisions and orders process.

The Information Exchange Requirements (IERs) associated with these have been a key focus and will be delivered to 2027 by three types of communications system:

- The existing Bowman system
- The FIST system
- A range of small scale, parallel communication networks employed to fill specific capability gaps where Bowman and FIST are insufficient.

Bowman will not support many new requirements for data communications, although it will remain the primary means through which command is exercised within Close Combat.

FIST will be able to support additional information requirements, such as logistics information reporting, richer situational awareness (SA) and ISTAR product distribution.

For greater range and/or bandwidth requirements, airborne nodes (based upon Unmanned Aircraft, tethered kites/balloons, aircraft or satellites) operating in the UHF/SHF bands will be used in parallel with Bowman and FIST.

In the table below we summarise the likely radio requirements for NEC4CC.

Radio	Timeframe	Key Characteristics
Generation 1	Now	Data and voice not simultaneous Voice priority (data blocked by voice) Single channel per network Low data rate (<40kbps)
Generation 2	2008-2012 for TRL 7/8	Simultaneous digital voice and data Multiple voice networks and subnets Medium data rate (<250kbps)
Generation 3	2012-2020 for TRL 7/8	Simultaneous voice and data Mobile ad-hoc networks, multiple modes and channels High data rate (<6Mbps) Packet capability (e.g. voice over IP)

Figure 4-2: NEC4CC classification of future soldier radios

In addition to research into the ground based tactical networks employed within Close Combat, NEC4CC has conducted a short task investigating the potential impact of airborne networks in CC. The task looked at the impact of airborne nodes on a number of specific scenarios. Key points identified from this task are:

- An SHF (10GHz) air-to-ground relay node would provide point-to-point SA between isolated elements within a convoy. Such technology also provides full motion video imagery to suitably equipped network participants. The airborne node may be UAV based (e.g. Watchkeeper in 2010 timeframe), helicopter based (e.g. a WAH-64 Apache upgrade in 2012 timeframe) or tethered helikite based (considered feasible within the 2012 timeframe).
- A UHF (300MHz) airborne (UAV node, linked to the terrestrial ground-based networks, would provide additional SA capability in a convoy and back to bases.
- Satcom on the move could bring major benefits in isolated CC such as improved SA within convoys. The expectation is that such capability would be provided down to Company level, and that this would use existing Satcom spectrum. Such technology provided by Skynet 5 is estimated to be deployable by around 2012.

Future Dismounted Close Combat

The Future Dismounted Close Combat (FDCC) programme is starting to identify concepts that place requirements on the spectrum. Specific requirements identified to date are:

- Increased demand for own-force location identification to support collaborative engagement activities will see new positioning systems adopted. UWB positioning systems will deliver improved location accuracy in the 2011 timeframe in scenarios where a UWB infrastructure can be established. Vision-based positioning systems in the 2015 time frame will feed back low-bandwidth position and environment structure information across the FIST network.
- It is expected that a variety of sustainability information, ranging from health status to ammunition levels, will be communicated over the FIST network.
- The demand for untethered devices on the helmet and weapon will see the introduction of Personal Area Networks on the soldier in future soldier systems.
- Collaborative engagement and sensor-to-shooter capability will be central to future soldier systems. The network requirements to support such capability have yet to be researched within FDCC.

Bowman

Bowman is likely to exist into the 2020+ timeframe. Future enhancements delivered through BCIPs are expected to focus on improvements to tools, applications and interoperability. Although use of the Bowman network is expected to increase, especially the use of HCDR networks, new frequency allocations are not expected.

We expect to see Bowman-FALCON interoperability within the 2012 timeframe, and two-way Bowman-FIST interoperability within the 2015 timeframe.

BCIP 5 provides additional capabilities over BCIP 4f including:

- Autonomous Situational Awareness
- Secure Data Services
- Messaging.

These will require data transmissions over and above the secure voice functionality of BCIP 4f. This will give increased spectrum demand in the near and medium term, probably contained within current allocations, though it may cause congestion.

Future Integrated Solder Technology

It is possible that the FIST radio could operate anywhere in the 30MHz to 2.7GHz band, even up to 4.9GHz. However, the physics of transmitting useful amounts of RF energy from near a human body, with a realistic antenna, to achieve tens of kilobits data rate over a distance approaching 10 km means that a VHF/UHF solution looks likely. The 225-400 MHz band is a popular choice for other NATO nations developing soldier radio systems.

The FIST Increment 1 C4I system is expected in 2010. Within the requirements there are no restrictions placed on the band within which FIST radios should operate, but compatibility with current and future ECM and force protection equipment is critical.

FIST Increment 2 is scheduled for 2015. Enhancements are expected to include 2-way Bowman interoperability and vehicle integration.   Therefore, it is likely (although not certain), that the radios procured and the spectrum required for FIST Increment 1 will be the same as those for FIST Increment 2.

In the table below we summarise examples of potential FIST C4I radios.

Manufacturer	Radio	Bands of operation	Power	Notes
SFF JTRS Radios	SFF-I	225 – 450 MHz	5W	Soldier radio for the US Army's FCS programme
	SFF-B	30 – 2500 MHz	5W	Soldier 'leader' radio for the US Army's FCS programme
Raytheon	DH500	22 5MHz – 2 GHz	4W	Low power, standalone version of Raytheon EPLRS radio
Harris	RF-300S-TR	225 – 470 MHz		The US SPR variant of the RF-7800S
	RF-7800S	350 – 450 MHz		
ITT	Soldier Radio	30 MHz – 2.7 GHz	5W	
	Spearnet	1.2 GHz, 2.4 GHz, 4.9 GHz		
ST@R	Mille-S	325 – 470 MHz		Demonstrated to Thales in Feb 08
Cobham	Eagle	2.4 GHz	100mW	Up to 5 hop MANet radio.
Kongsberg	SR600	225-400 MHz	10mW – 1W	Developed from Kongsberg's TACLAN radio

Table 4-1: Examples of Potential FIST C4I Radios

Enabling Secure Information Infrastructure

The ESII programme has identified 5 prioritised current capability gaps:

- Individual addressable battlefield communications
- Joint fires coordination
- Distribution of ISTAR products
- Over the horizon communications for disadvantaged maritime users
- Blue force positional information.

The programme has identified a wide range of communication network concepts that address these gaps including personal Satcom, civilian cellular technology exploitation and enhancements to systems such as Bowman HCDR and FALCON.

The majority of these concepts are expected to be achievable in the 2012+ timeframe. Many of these use existing spectrum. However, certain airborne communication relays may require new spectrum, as will the Joint Tactical Radio System Wideband Networking Waveform (JTRS WNW) which will require up to 30MHz bandwidth in the UHF band.

Competition of Ideas

Through the Competition of Ideas, Plextek have successfully demonstrated an 868MHz ultra-narrowband ad-hoc communications system designed to provide real-time situational awareness, text message communications and asset tracking for convoys (Appendix F). It has been described as providing a step change in capability, and could potentially be deployed immediately.

Unmanned Aircraft Requirements

Proliferation of large and small Unmanned Aircraft (UAs) is expected throughout the 2008-2027 timeframe (Figure 4-1). The demand for spectrum comes from two parts of the UA communication requirement.

- A need for low bandwidth links to control the UA. This incorporates the need for ground-to-air C2 link (10's of kbps), an air-traffic control channel (the existing VHF air traffic control channel) and UA-to-UA communications to support future concepts such as UA-to-UA refuelling in the 2015+ timeframe (requiring up to a few 100's of kbps).
- Payload communications. Typically the requirement is for >10Mbps capability to support full motion video or similar. Expect to see demand for communications to support SIGINT payloads on small UAs in the 2010+ timeframe, and to support full battle-management in the 2020+ timeframe.

The Rover 4 terminal, from L3 Communications, is widely used to receive imagery from aircraft on current operations operates in the following bands:

- 14.4GHz – 15.35GHz, 10.71Mbps
- 5.25GHz – 5.85GHz, 455Kbps
- 4.40GHz – 5.85GHz, 466kbps
- 4.40GHz – 5.85GHz, analogue

- 2.3GHz - 2.5GHz, analogue
- 1.71 – 1.85GHz, analogue.

The Rover 5 transceiver terminal, due to be released this year is expected to be widely used. It offers up to 44.73Mbps downlink, and includes an uplink. In general, increased use of such terminals due to proliferation of UAs over the next 20 years can be expected.

Large UAs, above 150kg, are expected to have additional capability requiring new communications links. In the 2015+ time period UA to UA in flight refuelling is expected, requiring high bandwidth low latency communication between UAs. In the 2020+ timeframe use of UAs for surveillance and for battle management is expected.

Military Communications Trends Chart from Research Programmes

Figure 4-3 below shows the key trends described above collected graphically.

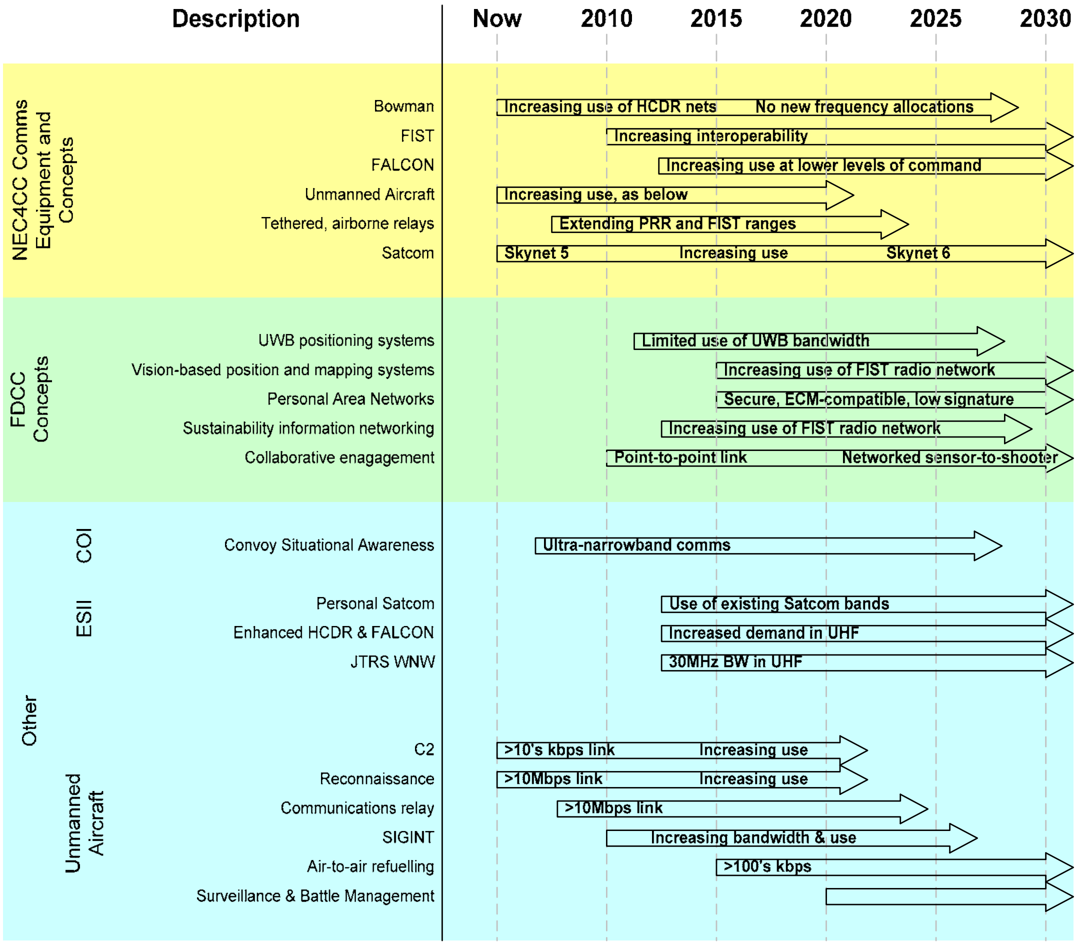

Figure 4-3: Military Communications trends by program and timeline

4.7.2 Developments in communications technologies

We have used PA's in-house technical expertise, along with that of other members of the team to make judgements about technical trends. In part this is based on our understanding of likely developments in key commercial markets (e.g. wireless technology and the mobile phone industry), but also on our understanding of the laws of physics. For example the band width requirements to transmit large quantities of high quality video imagery will frequently dictate a wave-length.

Dstl predict that defence communications technologies will continue to increase to meet capability objectives. The exact nature of technologies is difficult to forecast, but they will enable the transfer of data more efficiently and effectively. It is likely that boundaries between RF comms, RF sensing and EW will blur and will results in changes in specification of RF capability. RF demand by RF sensors will likely be a driver as these are developed and deployed. The management and use of the spectrum will likely become more flexible and agile using flexible spectrum dependent systems, more sophisticated information management and self synchronising spectrum access methods.

Trends

Any attempt to predict the future of technology is difficult. However, it is possible to suggest areas where benefits may be gained. In the medium term it is probably too late for new and speculative technologies to have much impact, unless they are part of current research activities. In the longer term, technologies designed to improve the use of spectrum have time to make an impact, if they are actively developed.

As electronic technology advances, wireless systems operating at higher frequencies become feasible. This will open up access to less congested spectrum with the potential for higher bandwidths. However the propagation characteristics are not as favourable as for lower frequencies and more accurate frequency references will be required.

Design for spectral efficiency

Historically, spectral efficiency has not been a key design driver for military communication systems. Other attributes, such as anti-jam (AJ), LPI/LPD, power economy, etc. features, have dominated. Achieving these can often be made easier if spectral efficiency is not considered too strongly in the design.

If spectral efficiency was to be a key design requirement, the demand for spectrum could be reduced. This might be at the expense of a more complex design or a necessary reduction in some other aspect of performance. If this latter point is unacceptable, then it may be necessary to introduce multiple modes of operation, e.g. spectrally efficient mode, reduced AJ capability vs. reduced spectral efficiency mode, high AJ capability.

Communications system design

Military Communication waveforms have traditionally been designed a set of individual links, whose performance is measured in isolation, rather than across the whole system.

There is evidence that this philosophy is beginning to change, with the advent of Mobile Ad-hoc NETwork (MANET) radio technology. In this technology, the performance of an individual link, e.g. range, is almost meaningless, as the system undertakes to transfer information using multiple hops. The principal object of MANETs is to improve connectivity, rather than improve spectral efficiency, though there is potential for it to contribute in this area.

Looking further afield to civil communication technologies; systems are designed to achieve very high spectral efficiencies. The drivers are limited spectrum availability and the commercial requirement to make the most of the spectrum asset. In the design process for these civil technologies, the system is considered as a whole. System wide simulation and modelling examine the effects of self interference, with the object of maximising system throughput, rather than individual link throughput. Of course civil communication systems do not have to deliver anti-jam or LPI/LPD capabilities, but applying this design philosophy to military communication systems should result in improved spectral efficiencies.

Compression

Many military data communication systems use text based message formats, e.g. ACP 127, VMF, etc. These invariably contain redundancy, requiring increased data exchange. If the redundancy were to be removed using data compression techniques, an immediate reduction in spectrum demand could be achieved. A study has shown that by using a simple, lossless compression technique, an ACP 127 message can halved in size.

A similar argument applies to voice communications. Many communication systems use simple, but robust, digital voice codecs, e.g. 16 kbps CVSD. Modern codec technology offers improved quality at a fraction of the bit rate. Codecs offering rates as low as 2 kbps are available.

Cross layer matching

The ISO Open Systems Interconnect model has been the keystone for communication systems design for many decades. It divides the communication process into layers, defining interfaces between them vertically and protocols horizontally between nodes. Each layer has its own function and apart from its upper and lower interfaces; it does not know how the other layers operate.

Whilst this leads to reduced design complexity and increased flexibility, it can lead to poor use of spectrum. This occurs when the higher layers; particularly the application, transport and network layers, do not take into account the operation and limitations of the lower layers, the physical and data link layers. One simple example is where a lower layer packet size is 100 bytes (say) and an application packet size is 101 bytes. The lower layer has to transmit two packets; the spectral efficiency is halved. If the application were to take the lower layer limitations into account, then this situation could easily be avoided.

Another effect is due to the legacy of the higher layers, derived from the fixed network, where bandwidth is effectively infinite, reliable and constant. This is just not the case when radio communication provides the lower layers. A simple example of this is the use of IP at the network layer. The minimum length for an IPv4 header is 160 bits, for IPv6 it is 320 bits, this is a large overhead when short packets of data are used. (Low latency VOIP might send 320 bits every 10 ms.)

There is no doubt that IP will continue to be used for many years to come and its successors are unlikely to impose a decreased overhead. In order to make the best use of the available bandwidth, the lower layers should take account of the higher layer protocols to avoid transmitting unnecessary overheads.

Dynamic spectrum allocation

Dynamic Spectrum Allocation has been seen as an opportunity to provide orders of magnitude improvement in the use of spectrum. The technique is based on the observation that although allocated and assigned, large portions of the spectrum resource are unused temporally and geographically.

The US Defense Advanced Research Projects Agency (DARPA) has been investigating alternative spectrum allocation methods for some time, in particular the use of dynamic spectrum access where equipment automatically uses spectrum that is instantaneously free. The following extract is from the DARPA website[20].

The Next Generation (XG) program goals are to develop both the enabling technologies and system concepts to dynamically redistribute allocated spectrum along with novel waveforms in order to provide dramatic improvements in assured military communications in support of a full range of worldwide deployments. U.S. Forces face unique spectrum access issues in each country in which they operate, due to competing civilian or government users of national spectrum. These constraints must be reflected in all force planning and may preclude operation of critical systems. Coalition and allied operations are even more complex to manage, and may severely limit the U.S. ability to fully exploit its superiority and investment in information technology. The XG program approach is to develop the theoretical underpinnings for dynamic control of the spectrum, the technologies and subsystems that enable reallocation of the spectrum, and the system applique prototypes to demonstrate applicability to legacy and future DoD radio frequency emitters. The approach plans to investigate methods to leverage the technology base in microelectronics with new waveforms, and medium access and control protocol technologies to construct an integrated system. The proposed program goals are to develop, integrate, and evaluate the technology to enable equipment to automatically select spectrum and operating modes to both minimize disruption of existing users, and to ensure operation of U.S. systems. The result of the XG program will be to develop and demonstrate a set of standard dynamic spectrum adaption technologies for legacy and future emitter systems for joint service utility.

Whilst this is interesting work, and is likely to ease frequency allocation in theatre, it is less relevant to use in the UK in the timeframes of interest for this study. In particular it is primarily intended to provide dynamic spectrum access for voice and data, rather than for radar systems. Additionally it does not primarily address the issue of overcrowding of spectrum, but focuses on selecting a suitable air interface option (radio channel, modulation type etc.) when there is capacity available. It could potentially provide limited bandwidth channels for use where necessary, perhaps to handle cases where demand exceeds supply, and would therefore overall increase the efficiency of spectrum usage.

However, in our opinion the technology is not yet proven and is unlikely to deliver results that would fundamentally change the conclusions of this report.

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[20] http://www.darpa.mil/sto/smallunitops/xg.html

4.7.3 Review of likely spectrum demand changes by 2027

In this section we discuss the spectrum implications of the technology changes discussed earlier, primarily from a communications viewpoint. They area summarised in Section 4.7.4. In this timeframe it is not possible to look at specific bands, and our approach has been to consider “VHF”, “UHF”, etc bandings.

VHF Spectrum Implications

The VHF spectrum commonly used for military use is the tactical 30-88 MHz band used by common VHF manpack and vehicle equipment such as Bowman VHF and Allied equivalents (e.g. US SINGARS). These are capable of both fixed frequency (commonly 25 kHz channel) and frequency hopping (up to full band). Above 88 MHz are broadcast and air-band uses, which prevent land tactical use of those frequencies. Some spot frequencies are harmonised as a NATO VHF Pool.

These radios are programmable to anywhere within 30-88 MHz but would require replacement to move the users elsewhere. Moreover, of the tactical (sub Theatre) equipments, mobile VHF equipment has the longer ranges (tens of km rather than single km ranges of UHF) and so users above Platoon or Company level would be reluctant to be moved off. Satcomm on the Move could be substituted but the costs are large, especially given the sunk investment in Bowman.

Currently modulation and message handling at VHF are not as advanced as at HF and UHF however this could easily change as the “VHF gap” (low data rates below Brigade level and above Platoon level) is now being recognised. Technology transfer to advanced modulation and coding techniques is only limited by investment, the potential for pull-through is there. This may mitigate the VHF gap by using spectrally efficient means but is not imminent.

There is some UK use of SCRA (currently MAPPS, derived from Ptarmigan SCRA) at spot frequencies above 100 MHz. This is highly prized as a wide area tactical asset by commanders and they are unlikely to want to lose it.

The UK specific argument is, again, that training of tactical forces in the UK is required as part of force rotation, etc. Currently military and civil users of the tactical VHF spectrum co-exist. It may be argued that geographical licensing within the UK (facilitated by PBSMS and a Commercial Spectrum Partner) could ease re-use problems here.

UHF Spectrum Implications

The military use of the UHF spectrum may be divided for convenience into: 225-400 MHz band, military 1400 MHz band and Other. There is also some UHF satcom (prized for the long wavelength), AWACS and BMEWS use.

UHF 225-400 MHz Spectrum

This is a busy NATO band, split into Land and Air uses by blocks. Air use is internationally harmonised and much legacy equipment with sub-optimum modes of operation persists, seemingly forever.

Military use, while under pressure from the civil side (e.g. T-DAB and TETRA (emergency services) and PMR), is strongly evolving as shown by the FIST programme mentioned above. FIST is an important part of the Dismounted Combat part of the NEC vision. FIST is the UK version of what are commonly called “soldier radio” programmes, other versions exist in the USA, France, Germany, Norway, etc.

All the ‘soldier radio’ programmes aim to provide digitisation benefits to small units in order to boost tempo and military effect. This is especially useful in scenarios such as counter terrorism (CT) and counter insurgency (COIN). The required data rate changes to enable this are an order of magnitude, from kilobits to tens-of-kilobits. Much of this will be provided by available enabling technology which will provide much more spectrally efficient transmission. However this will not ease military pressure for use and training of Land tactical UHF signalling as CT and COIN operations and training are much in evidence today. In addition ‘para-military’ uses such as security and NGO support also put pressure on this band as the enabling technology spills across to commercial products.

The short (tactical) ranges of this UHF band make geographical re-use of this band very attractive for land sub-bands. Obviously air uses are much less suitable for geographical re-use.

UHF 1400 MHz Spectrum

This is used for transportable, directional tactical wide area radio trunks (formerly TRIFFID in Ptarmigan, later will be FALCON and possibly HCDR). This is a major part of the NEC vision and will be required for field Division and Bridage level HQ functions, unless satcom on the move can substitute here.

There has been legacy investment here and the deployment is widely understood by Royal Signals. Their training facility at Blandford and transportable training equipment account for UK training assets.

Higher level modulation, compression and some spectrally efficient transmission have been implemented here historically to mitigate limited radio bandwidth compared to the growing demands of the linked IT systems. Scope for further improvement is probably limited.

This use being both limited in range and directional offers geographical re-use potential.

UHF Other Spectrum

BMEWS used a 400 MHz band and is unlikely to move, especially given the announcement of British support for an US BMD system. Link 16 / JTIDS shared a CAA band around 1200 MHz. Military GPS is internationally harmonised (around 1600 MHz).

There is a military band near 2100 MHz for mobile use that could come under pressure. This band is a possible one for air-ground relay but is also commercially valuable as it is near the sweet spot for low-cost civil RF components developed by the mobile phone industry. It also has a space use.

As noted above, the PEARL system is designed to use a small military band just below 900 MHz. This band is suitable for short range (shorter than the 225-400 MHz band and VHF) low data rate systems. It is also commercially valuable and near bands for ISM, GSM-R, PMR, etc.

The air navigation uses are harmonised and unlikely to move.

SHF Spectrum Implications

Part of SHF is the NATO 4.4 GHz band. This has potential use for applications such as very short range high rate communications (e.g. re-banded 802.11x applications), however this seems a priced band in the UK. Potential for geographic re-use is high.

Air radiolocation uses are likely to be harmonised and unlikely to move.

SHF is likely to be the prime band for wideband links to/from UAVs. This has a serious effect on spectrum use as UAV downlinks will impact a large geographic area leading to poor re-use potential (unless very directional, which may be problematic). For instance a High Altitude Long Endurance (HALE) UAV (or similar manned platform such as NIMROD) requiring 10 MHz, say, on exercise over the UK means that the 10 MHz potentially suffers interference anywhere in the UK and cannot be reused. This argument is similar to the one which means that the UK Home JTIDS deployment is always limited to a single net.

There are many SHF military satellite bands. As SKYNET is already a Public Private Partnership there is limited future scope for further trade-off between civil and military satcom use. Moreover MOD already utilise rented INMARSAT and IRIDIUM civil links for military uses, so pressure here seems outward rather than inward.

EHF Spectrum Implications

The UK military EHF spectrum is NATO satellite bands. As SKYNET is already a Public Private Partnership there is limited future scope for further trade-off between civil and military satcom use.

4.7.4 Implications Summary

Figure 4-4 summarises the key points from this section on future spectrum implications from changes in communications technology.

Band	Frequencies	Main uses	Trend / Drivers
VHF	30MHz – 300MHz	Various, principally mobile	Use for tactical training with Bowman VHF expected to continue
UHF	300MHz – 3GHz	Various	Increased demand for soldier radio systems (most likely in the 225-400MHz region) Increase in demand to support FALCON and Bowman HCDR Potential for increased demand near 2.1GHz for air-ground comms and relays Potential for demand just below 900MHz to support short range low data rate systems Air navigation use is unlikely to change
SHF	3GHz – 30GHz	Various, including satellite	Increased demand from Unmanned Aircraft
EHF	30GHz – 300GHz	Satellite	No change suggested by research

Figure 4-4: Spectrum implications – High level summary

4.8 RADAR TRENDS TO 2025

4.8.1 Developments in Radar Technologies

Ofcom commissioned "A study into the spectral efficiency of radar systems in the L and S bands." The final report is available on the Ofcom website at http://www.ofcom.org.uk/research/technology/research/ese/sers/. In summary, the study proposed three options for freeing the attractive spectrum to commercial applications:

- Shift
- Squash
- Share.

Shift: the possibility of using alternative bands for radars is discussed in the band-by-band analysis.

Squash: the second option is to improve the spectral efficiency of the waveform. Such waveforms would require highly linear power amplifiers, as opposed to the class C amplifiers used in the current pulsed radars. Linear power amplifier technology is predicted to be available by 2011, so this approach could have an impact on the medium term. For the longer time frame, continuous wave radar technology is identified; though the report predicted that this would not be available until 2016 to 2021 as there are a number of technical problems to be overcome.

Share: the final option is to share the radar bands with other users. The report states that this option would not be feasible until the advent of CW radars, since the other users would have to monitor the radar transmissions to avoid interference.

In this section we consider the potential of 'Squash' and 'Share' approaches with the expected evolution of radar technology over the next 20 years.

4.8.2 Key questions

The purpose of this paper is to discuss the possible evolution of radar over the next 20 years from the point of view of spectrum usage. The major questions to be addressed are:

- Will radars use less spectrum to achieve the same capability as presently
- Will they use the same spectrum for more capability
- Will they use more spectrum for more capability
- Are the various different radar systems around the UK likely to become more or less integrated
- Will the ability to share frequency allocations between radar systems change significantly over the next 20 years
- How sensitive is the design and implementation of radars to the cost of a given spectral band?

The 'Technology and Developments' section that follows discusses the main developments we see in radar; this is followed by specific discussion of the questions above. As background, Appendix G provides a brief overview of the main radar systems in operation today.

Technology & Developments

A large area of research activity in radar is devoted to signal processing and information extraction and, as such, do not have a direct influence on spectrum usage. Developments are ongoing in transmitter technology to derive more linear, better controlled transmitters, and in waveform design to extract more information from objects and to reduce the impact of jamming on radar operation. There is burgeoning interest in passive radar for their flexibility, covertness, cost and deployment. This technology, although there are several such radars on the market (Lockheed Martin's Silent Sentry 0 or Thales Alerter HA-100 0, both using analogue FM transmissions), is still immature and unproven. Further development is required before they can be routinely used in place of, or in addition to, existing active radars.

Transmitter Technology

In nearly all developed radar systems, including the current state of the art, the transmitter is operated in class-C (saturated non-linear) with fast pulse rise and fall times.

Linear radar transmitters are not achievable with existing solid-state technology. Multiple amplification stages are required to amplify the low power of solid-state power transistors. Operating each stage in its linear region of operation is difficult. Nonlinear transmitters tend to generate highly rectangular, and spectrally inefficient pulsed waveforms.

Recent technology advances have lead to the availability of high power near-linear solid state LDMOS technology in L-band and its emergence in S-band. Since waveform spectral efficiency is largely controlled by pulse rise (and fall) time significant improvements can be achieved with this technology using shaped pulse edges. Novel pulse-shaping schemes, such as Taylor quadriphase (a type of phase-coded modulation), which require linear amplifiers, may then be usable.

LDMOS technology is at a stage such that practical radar transmitters could be developed within 5 years, and would be the best candidate for future civil and military ATC.

Currently and over the next four to five years NATS will be procuring Raytheon ASR 10-SS radars, to replace existing civilian ATC and military primary surveillance ATC radars. These operate at S-band (2700-2900MHz) with frequency diversity (four frequencies) and use solid-state technology to provide a transmitted spectrum that is compliant with NTIA requirements. These provide close to the best spectral efficiency of current radar technologies, cf. the 2.5MHz bandwidth of Watchman with the 1MHz bandwidth of the ASR 10-SS, in addition to the latter's slower rise/fall time of pulses. These radars will have a lifetime out to 2025.

Waveform Technology

Work is continually ongoing in the radar field to develop new waveforms which provide new, desirable properties to the radar user. This is largely driven by the military "market" as civilian radars have much more well-defined and established requirements. For military radars the problem of being jammed is of major concern. With the growing interest in stealth technology and use of platforms with small RCS, e.g. UAVs, the detection and recognition of "small" targets is also an ongoing area of research. Some of the technologies open to the waveform designer to achieve these objectives are coded waveforms and low probability of intercept (LPI) waveforms.

The concept of LPI (spread spectrum) waveforms is to transmit a modulated waveform over a broad spectrum but at very low peak power. Correlation techniques are used to detect these waveforms in co-operative receivers. Due to the low peak power they are not readily interceptable and/or detectable by non-co-operating receivers. If LPI waveforms were adopted by civilian radars the impact of such technology would be to reduce the frequencies required to be transmitted, due to the reduced interference between the radars. Judicial spacing of the radar sites, whilst still maintaining airspace coverage with the required redundancy, would also assist in reducing interference between the radars. This requires a redevelopment of the radar transmitters and receivers to accommodate the novel waveforms. This must be seen as requiring a minimum of 10 years of development to implementation of a full system, not including assessing the required safety and reliability performance of these systems.

Coded waveforms can be designed which are orthogonal, i.e. have little correlation, to each other. A good example of this is the Coded Orthogonal Frequency Division Multiplex (COFDM) waveforms used by DAB and DVB-T. In the DAB network, for example, the transmissions are generally operating in a single frequency network, where each multiplex (group of radio stations) are transmitted in a single band (approximately 1.7MHz). Orthogonality provides the degree of separation required to discriminate between different stations. Error correcting mechanisms are present to provide a robust system. The amount of orthogonality achieved in practice in the DAB or DVB-T network preclude their use in radar. However, it is entirely feasible that waveforms exists which can provide better orthogonality.

Some coded waveforms have an intolerance to Doppler (radial velocity) imparted by moving objects resulting in reduced detection and resolution. Other schemes, such as polyphase coding, are more tolerant of Doppler, but are not yet widely adopted.

Time and frequency multiplexing techniques, again although heavily adopted in communications systems, are not readily used in radar systems. A degree of co-operation is required between radar users to manage the transmitted waveforms so that signals are not transmitted on the same frequency or at the same time as other users. It would be reasonable to expect that these techniques, if feasible, are adopted along with the other techniques described above, primarily the LPI waveform concept. High time synchronisation, via GPS or atomic references disciplined by GPS, is readily available and ready for adoption.

Other waveform concepts, such as the Taylor Quadriphase modulation, require highly linear transmit devices which are not currently available. Slow rise and fall time of pulses from these schemes result in reduced range measurement accuracy of objects. Processing needs to be improved to regain the accuracy required.

Reduced bandwidth waveforms may also be considered. These would be similar to current waveforms but sacrifice resolution for less bandwidth. To recover the range resolution used by conventional systems novel techniques such as superresolution may be used. Algorithms, such as MUSIC (and its many variants), Maximum Likelihood (ML), Bandwidth Extrapolation (BWE) and Parametric Target Model Fitting (PTMF) currently exist as research tools but it is not known whether any of these exist in current radars. A major problem with some of these techniques is the need for high signal to noise (SNR), particularly where discrimination between targets is required. High computation cost is another disadvantage, but this can generally be overcome in time.

Passive Radar

Passive radar offers good opportunity for spectrum re-use. These types of radars do not transmit at all but use existing transmitters, for example, commercial systems such as DVB-T, DAB and cellular mobile phones, for the transmission waveform. One or more receivers are placed so that reflections from objects are intercepted. Correlation techniques are used to provide information on these objects (bistatic Doppler and time-difference of arrival). Obtaining such information from different transmitter-receiver pairs allows the object to be geo-located.

Due to the nature of commercial transmissions, passive systems are constrained by their elevation coverage. Unless the commercial transmitter is very powerful (as with the analogue FM transmitters in the United States) elevation coverage is relatively low level (up to several thousand feet).

Passive radar systems are potentially capable of augmenting the civilian ATC network for low-level, short range (<100km) detection and tracking of aircraft. However passive radar is not a mature, proven technology and it unlikely that a robust, practical system will be available within the 20 years timeframe. Higher-level and longer range coverage will still need to be maintained by active radars.

CW Radar

CW radar systems have the potential to reduce radar spectral requirements. They use unmodulated continuous-wave, i.e. un-pulsed, waveforms, but because of their lack of range measuring capability they are not widely adopted. However, Doppler and angular information is readily available and these may be processed to provide some target geo-location capability. A multistatic (multi-site) system would be a likely configuration for a CW system to overcome the ambiguity in determining target location, however this has its own difficulties including the need for synchronisation of measurements between different sites. Self interference reduces the use of these networks for long-range surveillance. Tracking algorithms need to be specially developed to work with Doppler and angle only (as opposed to conventional radars which also use range).

There are a number of other limitations including their susceptibility to interference and their inability to directly measure range which precludes their widespread use in civilian and military functions. The solutions for these limitations are as yet immature. This means that there are a number of significant technological hurdles before CW systems can be accepted as feasible for the provision of civil or military ATC services. It is unlikely that any CW radar product for ATC purposes will be available to the market within the next 15 years.

4.8.3 Will radars use less spectrum in the future to deliver the same level of capability?

Current

Currently radars use analogue Linear FM and non-linear FM waveforms to achieve high range resolution with long pulses and consequently higher mean power. The newest ATC radars use nonlinear FM with long pulses. With current transmitter technology (assuming maximum duty cycle of approximately 10%) these offer the best spectral efficiency possible in current radar systems.

2015

By 2015 linear solid-state transmitters should become available. This will tie-in with the expected replacement/upgrade of existing military ATC systems. These linear devices will permit pulse shaping techniques to be used, providing significant spectrum efficiency over current radars without affecting its capability. In addition, linearity in the transmitter leverages the potential for using coded waveforms. These waveforms have the potential for reduced interference between users (c.f. DAB radio network). Many of these waveforms currently suffer from a number of disadvantages and so require research to overcome these before they can be adopted.

Better co-operation between existing radar users should be possible. Technology exists, but needs to be adopted, to time synchronise transmission between different radars so as to reduce interference. Many ATC radars, particularly in the dense South-East of the UK, are good candidates for such co-operation.

It should be possible, certainly in peacetime, for the coverage of UK AD radars to be controlled so that, say, blanking is used to avoid transmission over inland areas whilst maintaining coverage over sea. Inland areas without coverage may be serviced by shorter range, higher frequency (e.g. X-band) radars. As with ATC radars, there is the potential for better frequency and time multiplexing between radar users.

It should be feasible for existing onshore S-band radars to reuse marine (vessel Tracking System) radio-navigation frequencies (2900MHz to 3100MHz) inland where their coverage is not required. Terrain screening and other co-channel interference suppression, such as waveform features, e.g. orthogonality, PRF, agility, could improve the ability to achieve this.

2025

In this time-frame CW systems may become available for the ATC market provided work is ongoing now to develop these into products. Over a similar time-frame passive, bistatic or multistatic radars may be sufficiently mature to replace some short range ATC radar systems. either through exploitation of commercial transmitters or through introduction of new specialised transmitters. The latter will be probably of more interest to military users due to the reduced reliance on 3rd party transmissions which are not guaranteed to be operational for these users.

Overall we might expect to see an improvement of perhaps 10% in spectral efficiency in this timeframe due to the introduction of CW radars..

4.8.4 Will they use the same spectrum for more capability, or more spectrum for more capability

Current

Current systems perform a number of different activities. Bandwidth may be used to provide high range resolution for improved detection and localisation of objects. ATC radars in current operation are designed to meet particular CAA and other requirements, e.g. 0 and this defines their bandwidth usage. They are not required to meet any particular level of spectral efficiency.

Research is ongoing in a number of different areas to utilise more bandwidth for providing more additional information content of detected objects. A key activity is high range resolution target recognition using various techniques, such as inverse Synthetic Aperture Radar (ISAR). Recognition depends on identification of the principal scattering centres of objects which is then classified either by associating with an existing measurement in a database of known objects or its principal dimensions inferred directly from the measurements. Target recognition capability is not yet mature enough to be used reliably.

2015

It should be feasible to replace a number of large powered S-band ATC radars with shorter range, but more numerous X-band radars providing the same or better coverage.

Target recognition may be of sufficient maturity to be adopted by AD radars. It is not envisaged that ATC radars would require this functionality.

2025

Systems which exploit LPI waveforms should be deployable allowing freeing up of large parts of the ATC S-band spectrum.

There may be demand over the next 20 years for increased use of unmanned air vehicles (UAV) for improving ground surveillance, e.g. for homeland security purposes such as border control. Sensors on these platforms will need to co-operate with existing users.

4.8.5 Are the various different radar systems around the UK likely to become more or less integrated (i.e. fewer or greater number of sites)

Current

There is little integration between the different radar systems in the UK due to the lack of necessity (political) for doing this. The weather radar network is suitably designed that coverage of the UK is optimised. There is potential for this to be achieved in the ATC and, to a lesser extent, the AD network.

2015

The introduction of shorter range X-band radars to replace longer range S-band ATC radars is a possibility in this timeframe.

2025

Passive radars may of sufficient maturity to replace a number of S-band or X-band ATC radar systems in this timeframe.

4.8.6 Will the ability to share frequency allocations between radar systems change significantly over the next 20 years

Current

There is little co-operation in terms of frequency allocation by current radar systems due to the lack of a need to achieve this.

Weather radars operate at 5.35GHz to maximise returns from rainfall whilst maintaining adequate range. Any shift to lower frequencies would degrade their functionality since the ability to detect rainfall is much reduced at lower frequencies.

The lack of overlap between AD and ATC radar function, the former long-range and higher elevation, the latter shorter range and lower elevation, precludes their ability to share frequency allocation.

2015

The reuse of the marine navigation frequency band by onshore, i.e. ATC, radars is feasible in this timeframe. There is also potential for radars within a network (either AD or, more likely, ATC radar) to co-ordinate transmissions through time synchronisation techniques.

Linear solid-state transmitters should be available permitting more spectrally efficient waveforms to be used. This would allow radar users to be more closely spaced.

2025

With linear transmitters in widespread operation and further research in spectrally efficient waveforms, processing and synchronisation being made a more co-ordinated policy on frequency sharing should be possible.

4.8.7 To what extent is price of spectrum likely to be a significant in defining design and operating bands of radar systems e.g. with AIP costs of £10k/MHz/year, £100k/MHz/year, £500k/MHz/year

There is little doubt that the advent of AIP in the main L&S radar bands may well result in significant sums of costs to radar users. The original guide for earlier phases of this study contract used a guide price of £238k/MHz/pa for the priority 2.7-3.1GHz S-Band, with a lower rate of £118k for 3.1-3.4GHz and no specified rate in L-Band (1250-1350MHz). This would result in annual sums of £67m for 2.7-3.1GHz and £36m for the 3.1-3.4GHz bands.

More recently an Ofcom consultation[21] on Aeronautical and Maritime spectrum formally proposed a £126k/MHz/year in the table below for both L-Band and S-Band.

Band	Reference rate for 1 MHz of national spectrum
Aeronautical secondary surveillance radar (1030/1090 MHz)	£126,000
L band radar (1215-1350 MHz)	£126,000
S band radar (2700-3100 MHz)	£126,000
X band radar (9000-9500 MHz)	£17,000
Actual assignments are not national, and licence fees, once apportioned, will reflect the geographic impact and bandwidth use of each installation.	

Figure 4-5: Proposed Ofcom rates as at August 2008

These would result in approximate charges of £50.4M/pa for S-Band and £17M/pa for L-Band which would need to be primarily apportioned between MoD and CAA. Given the large number of assignments in S-Band, resulting in smaller pro-rata charges per installation/licence, some care needs to be taken not to undermine the assumed priority that clearing the lower part of S-Band is the main focus.

In a previous review for Ofcom, BAE Systems considered typical prices for development and modification or production of shorter range airport traffic radars (NOT longer range air defence radars). Modifications for receivers to have improved signal processing to mitigate interference were considered to be around £3m per development case and £750k per unit. Replacing transmitters were viewed as similar development costs but ~£1.3m each to deploy, whilst an overall new radar design was seen to be of the order of £14m to develop and £2.5m per unit. Costs associated with longer range air defence radars are higher and the production runs to amortise over are much shorter.

21 "Applying spectrum pricing to the Maritime and Aeronautical sectors", Ofcom website http://www.ofcom.org.uk/consult/condocs/aip/, Opened 30-Jul-2008, Deadline 30-Oct-2008

If AIP rates were only £10k/pa and opportunities to pass these costs on to airlines/airport operators were available, then there would probably be little incentive to change equipment design and specification. At £100k/pa the perceived savings in spectrum efficiency if, say, only the lower 100MHz section of S-Band could be cleared, saving £15m/pa, probably would be an effective incentive to consider in future clean-sheet designs but the time to realise these savings may be significant due to development and certification timescales. Price rates in the £500k/pa bracket would undoubtedly have a major impact, but are not foreseen at present.

This should be seen in the context of a typical lifecycle for a radar design of 15-20 years, so it is conceivable that if a stable regime was put in place now it would incentivise developments of lower TRL technologies read for deployment in the 2025 timeframe.

Long range air defence systems in some respects hold the key to replanning S-Band for generating economic savings to the radar operators as well as economic gain for spectrum release. Intelligent setting of AIP rates may encourage L-Band rather than S-Band for future long range air defence designs (though this a long term given the new Commander SL radars currently being procured).

Some new radar technology options require wider bandwidth waveforms that offer new military/operator capability, but could also accommodate increased sharing in S-Band and AIP rates might encourage this.

Some inland shorter range airport radars (in the 2.7-2.9GHz range) could be economically retuned into parts of 2.9-3.1GHz, or if incentives were available be substituted by new C-Band radars that would operate in the 5GHz band, similar to the weather radars. For this latter option there has to be some focus and central direction to encourage development as there are few if any C-Band products for the ATC market. One possibility would be to channel AIP funds to radar equipment development to accelerate this.

Elsewhere this report considers technology options most of which are considered to be feasible, but very few feature in current market offerings. The midrange AIP rates will have an impact, but flat AIP rates may not be the best tool if a particular band is a priority. If AIP is to be effective and quick acting, consideration should be given to route funds to equipment developers.

4.8.8 Summary

UK Radar systems cover several functions, but the major ones are ATC for en-route and terminal manoeuvring of aircraft, including military, in UK airspace, long-range surveillance and tracking of airborne objects (air defence) and Met Office rainfall and wind profiling radars. The first two of these types mainly occupy L and S bands whilst weather radars operate at C-band. Pulsed waveforms, unmodulated or modulated, are generated by Magnetron or TWT transmitters. Newer transmitters currently being introduced use solid-state devices which are difficult to operate linearly. In the next five years more linear solid-state transmitters should become available. With this should be the capability to better control the shaping of pulses for transmission allowing reduction in spectrum usage, although at present it is difficult to forecast an improvement of greater than 10%.

Developments in waveform technology, such as reduced bandwidth signals (e.g. coded waveforms) and LPI waveforms can leverage freeing up of parts of L and S-band spectrum. The former is obvious; the latter would permit radars with overlapping coverage to operate more closely together, or on top of each other, in frequency. Most of these techniques would probably require redesigned transmitter and receiver systems. Signal processing techniques, such as super resolution, may be able to recover range resolution but need development to assure robust operation in marginal, i.e. low SNR, situations.

A greater co-operation between existing users is clearly desirable. Synchronisation between sites would permit reuse of the same frequency band amongst users. Technologies to achieve this are currently available but need to be pursued.

Shifting the use of some frequencies (S-band) to higher, less used frequencies such as X-band is possible. Although shorter range, a larger number of X-band radars could feasibly replace a smaller number of S-band radars whilst providing the same coverage. Moving to higher frequencies is not without its disadvantages. Less resistance to atmospheric and climactic conditions constrain the operational ranges of these radars. The higher beamwidths associated with these radars compared to S-band radars means that the scan or search rate of these radars must be increased to maintain the overall search time of the surveillance space. This entails greater processing requirement.

Similarly, the reuse of marine navigation frequencies for onshore radars is a possibility provided there is sufficient protection against mutual interference.

Passive radar techniques are a current research activity and, whilst currently immature, may replace a number of active radars for low elevation short range operation. The use of 3rd party transmissions precludes their use in the military domain unless dedicated transmitters are deployed with their concomitant costs. Their use in an air defence role is not expected due to their lack of high elevation and long range capability. The latter is achievable though, as shown by the Silent Sentry system, but requires high power transmitters. The move to lower power digital transmitters in the UK removes this ability.

It is feasible that multistatic CW systems could fulfil an ATC role, but the technical challenge of geo-locating and tracking objects through Doppler and angle, without range information, and avoiding mutual interference means that deployment will take some time.

References

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http://www.eads.com/1024/fr/pressdb/pressdb/20080527_eads_ds_de_passivradar.html
CAA, “CAP 670: Air Traffic Services Safety Requirements”.

4.9 OVERALL EFFECT ON SPECTRUM DEMAND TOWARDS 2027

This section looks at the trends in different systems and applications moving towards 2027. It does this considering the categories of "spectrum using" equipment defined in Section 2.1, i.e.:

- Voice and Data Links
- Navigational Aids
- Defence and Weapons Radars
- Other (e.g. satellite comms, data / telemetry links).

For each of these categories, we then look further at the trends affecting the basic parameters of spectrum demand of:

- Channel bandwidths
- Volume of use (i.e. number of channels needed)
- Frequency bands used / needed
- Area(s) of use.

From this, we comment on what this will mean overall for spectrum demand for each category, in terms of overall growth or reduction in demand and where in the spectrum this will be located.

4.9.1 Voice and Data Links

This category includes:

- General purpose voice and data comms
- Air-Ground-Air (AGA), Air-Air (AA) comms
- Tactical data links.
- Tactical voice and data
- Tactical trunked radio

General purpose voice and data comms

General purpose voice comms - such as site security voice, may be consolidated and moved onto 3rd party networks (e.g. Airwave). For most of these applications, the range possible at 225-450MHz is not strictly needed and could be moved to higher frequencies, particularly if other commercial mobile operators in the UK begin to meet the security requirements on their networks as they move towards 4G networks and beyond.

- Overall MOD spectrum demand to reduce – Voice comms volumes are not likely to increase, channel bandwidths will decrease with technology improvements and voice services are likely to migrate onto 3rd party networks.

Data Comms - MOD, as with the rest of the UK, is likely to see a large increase in the use of general purpose data comms (as offered by WLAN today), particularly with growth of secure wireless LANs. However, these are likely to remain in either commercial or unlicensed spectrum, rather than create demand for MOD-specific spectrum.

- No change to MOD spectrum demand.

Tactical voice and data comms

Operating range is key to tactical comms (both voice and data) which are likely to remain at relatively low frequencies (70-88MHz, ~150MHz and 225-450MHz).

Tactical voice comms traffic could change with the introduction of FIST and NEC, as we move more information down the chain of command to the individual soldier. We note that the FIST programme anticipates rolling out many thousands of radios in the UHF bands; these could replace the 'Personal Role Radio'. However, our view is that the majority of the traffic increase will be in data comms (see below).

Tactical data comms is likely to increase significantly in volume. Networking of soldiers will become increasingly important with higher and higher volumes of data being passed around the battlefield (and therefore also in training in the UK). Passing of data between soldiers is likely to progress to images, then to full-motion video. The introduction of FIST is set to reinforce this trend and moving towards NEC by 2027 will continue it further.

- Tactical data volumes (both channel bandwidths and number of channels) are set to increase significantly. We expect the 225-450MHz bands to become increasingly in demand for such services and we could well see such applications being forced to move into higher frequencies as well (e.g. 1GHz – 2.5GHz) to achieve the data throughput volumes that may be needed.

- Depending on the communications architecture a Company sized deployment might require between 1 and 10MHz of spectrum in the UHF band, which could demand between 10 and 50MHz for a major exercise on Salisbury Plain.

Air-Ground-Air (AGA) and Air-Air (AA) comms

A/G/A and A/A voice comms are not likely to see much change by 2027. Due to range requirements, these currently sit in the 225-450MHz bands and are likely to remain there. Channel bandwidths may reduce slightly with technology advances, but these systems are already typically using channel bandwidths of 8.3kbit/s or 6kbit/s, so further improvements are unlikely to be significant.

Air-to-Air data comms has potential to increase significantly. Demand increase may overlap with other applications and users, such as UAVs and tactical data links, as data (including video and telemetry data) is shared between manned and unmanned aircraft. Depending on required ranges, such links could sit anywhere from 2GHz up to 20GHz.

- Air-to-Air data comms may increase significantly. Channel bandwidths are likely to be significant (> 10MHz) and operating frequencies will be from 2GHz to 20GHz. This could require in excess of 100MHz, and would need to be placed at relatively high frequencies (perhaps 4-6GHz, and 10-20GHz bands).

Tactical trunked radio

Tactical trunked radio systems will move towards higher and higher channel bandwidths as the volume of data (imagery, video, commands, etc) to be transported around the battlefield increases and as mesh networking technologies improve. This trend is in place, with FALCON to replace Ptarmigan in the next few years. This move to higher channel bandwidths will force systems to move towards higher operating frequencies.

Channel volumes required (especially for training in the UK) are not likely to increase, and may actually reduce as advances in antenna technology may result in better directionality of links, better out-of-channel emissions and lower inter-link interference.

- Channel throughput to increase (from 500kbit/s – 2Mbit/ today to Nx10Mbit/s in the future). Demand to fall in the 225-380MHz band (due to lack of available spectrum), with growth in demand at 2GHz, 4.4-5GHz, 15GHz and above 20GHz.

Tactical data links

Tactical data links are likely to have increasing demands placed on them as data volumes to be passed increases. JTIDS Link 16 may still be in place by 2027, but other systems are likely to be needed to cope with demand. Operating ranges are a major restriction on higher frequencies between ships and planes, but there is likely to be a requirement for other (wider bandwidth) systems at higher frequencies. Whilst operationally it might be important to have long range, it may be possible to use shorter ranges in the UK).

Summary

Overall, increases in tactical data is going to see significant increases in demand on MOD spectrum from a number of systems required to pass this data around (man-portable radios, trunked radios, tactical data links, air-to-air links).

The 225-450MHz bands are likely to remain busy with systems such as FIST (and its successors) being introduced. Higher operating frequencies are likely to be used for such links, driven by the need for wider channel bandwidths but restricted by required operating ranges. Some airborne systems and short-range trunked radio systems are likely to move above 15GHz, but other applications will need to sit from 1GHz-2.5GHz and “spare” spectrum could well be commandeered between 4GHz and 6GHz.

4.9.2 Navigational Aids

This category includes:

- Airfield navigation and surveillance enablers
- Airborne navigation aids
- Maritime navigation aids.

We don't believe there will be significant changes in spectrum demand from these systems, even by 2027.

Much of the airborne systems and operating frequencies have to be cleared for international use and are not the sole decision of the MOD. Furthermore, many of these systems are restricted in operating frequency by required operating range and migrating to higher frequencies may well simply not be feasible.

The 2700-3100MHz and 9000-9500MHz bands are likely to remain key.

4.9.3 Defence and Weapons Radars

This category includes:

- Air Surveillance And Control System (ASACS)
- Tactical surveillance radar
- Weapon guidance radar
- Airborne detect & track radar
- EW simulation of red systems
- Counter-battery radar.

Surveillance, detect & track and weapons guidance radars

Within this category, those radars associated with surveillance, detect & track and weapons guidance are likely to place increasing demand on the MOD spectrum. This is a trend that can be seen with the wide-band radars being introduced on the Joint Strike Fighter. These systems are likely to see continuing congestion in 8.5-10.5GHz and 13.4-15.2GHz.

It is not currently clear what other operating frequencies these systems will migrate to, as and when increasing demand forces the MOD to look to greater capacity elsewhere. It is likely to see systems operating above 15GHz, moving up towards 25GHz in search of capacity to accommodate operating characteristics.

There is a prospect of technology advances helping such radars to co-exist in the same frequencies, reducing overall spectrum demand. Equally, improvements in inter-platform data links (ship/ship, air/air, air/ship) might conceivably see an effective sharing of radar systems (i.e. one radar system sharing its data in real-time with multiple entities), also reducing overall spectrum demand.

- There seems to be an inevitable trend towards ever wider channel bandwidths for these radars. This will see ongoing congestion in the existing 8.5-10.5GHz and 13.4-15.2GHz band, with future demand placed on higher frequencies, certainly up to 25GHz.

Other radars

Assuming that the threat profile to the UK does not change significantly in the period to 2027, other radar systems, such as the ASACS radars and counter-battery radars are not likely to see great changes by 2027. These systems are restricted by operating characteristics such as range and resolution that means they cannot easily move significantly higher in frequency. Also, the volume of these systems (certainly in terms of use in the UK) has no great reason to change significantly by 2027.

Summary

Surveillance, detect & track and weapons guidance radars will place ever-increasing demands on MOD spectrum, resulting in ongoing congestion around 9GHz and 15GHz, with probable further demand for higher frequencies. Improved technologies such as CW radar may improve efficiency but this could be absorbed by increased capability requirements.

4.9.4 Other (e.g. satellite comms, data / telemetry links)

This category includes:

- Satellite communications
- Data / video / telemetry links
- Fixed point-to-point microwave links
- Other radar.

Satellite communications

There is likely to be an increase in demand for satellite communications, particularly driven by the need for greater volumes of data to be passed between various MOD parties and locations.

Demand for spectrum in the current Skynet band is likely to continue and with the prospect of additional spectrum needed to augment capacity. As with any demand for higher bandwidths and capacity, this is likely to occur at higher frequencies.

However, such satellite communications will need at least some level of international coordination. As such, expansion of MOD satellite communications will have to either move to commercial systems (meeting security requirements) or open up new spectrum.

Data / video / telemetry links

This is an area that is likely to grow very significantly by 2027. There is already clear growth in the use of wide-band data links to pass various types of information between platforms.

UAVs are probably the clearest example of a platform using such links that is bound for large future growth, but other systems, such as ASTOR, are already moving in this direction. This overlaps with the comments mentioned above under Air-to-Air data comms.

In order to alleviate congestion and over-demand, it is probably vital that the MOD procure a small number of strategic systems to provide these links that can be re-used across different platforms. Such a trend can already be seen to be in place with the Common Data Link (CDL), providing wide-band data links for ASTOR, Watchkeeper and the Raptor pod on Tornados.

Technology advances, particularly in antenna design, may well be able to alleviate some of the demand for spectrum by increasing frequency re-use between users by increasing directionality of transmission (e.g. through automatically beam-steering) and reducing interference between users.

Fixed point-to-point microwave links

MOD demand for spectrum for such links should reduce over time. There are many 3rd parties providing such links in commercial bands cost-effectively and efficiently and, in principle, there is little reason for the MOD not to use these service providers for these requirements. Alternatively, MOD could equally set up its own links in civil bands on the same basis as other users.

Other radar

These radars include range safety radars and aerial target radars. These are specialist uses and systems and are not likely to see any significant changes in demand, even by 2027.

There is some prospect of spectrum demand reducing for these systems as newer, more spectrally-efficient systems are developed, but this will not have a great impact on MOD spectrum.

Summary

Satellite communications will result in greater demand for spectrum, as this is a key bearer for transporting ever-increasing volumes of data between parties and locations. The Skynet services band will continue to be congested and new frequencies are likely to have to be opened up (between 10GHz and 20GHz.

Data and telemetry links are going to grow in importance and, subsequently, in spectrum demand. These already use a lot of spectrum in the 2310-2390MHz and 8500-10125MHz bands and may need further spectrum above 10GHz to meet future demand.

5. METHODOLOGY

5.1 INTRODUCTION

We considered a number of different methodologies for the economic modelling aspect of this study, including:

1. Multivariate regression across a dataset of international comparables, as used for example by Hazlett[22] to assess civil demand for spectrum
2. A time-series approach, focusing on UK demand and MOD data
3. A requirements-based model taking data from stakeholders regarding present and future demand, from which to calculate the economic impact

Multivariate Regression

The cross-sectional international comparisons suffer from a lack of good international comparables, and the large differences in defence capability requirements and priorities observed even between the similar economies and societies such as those of the UK's nearest neighbours in Western Europe.

Simple differences such as the role of the nation within international treaty organisations such as NATO, their differing requirements for land / air / sea defence, and their differing status on the world political stage make comparables unreliable. Any effect from AIP tariffs is likely to be a long way down the list of influences, making any quantification of its influence via multivariate methods somewhat suspect.

Time-series Approaches

The time-series approaches suffer from the lack of a realistic underlying noise model. The biggest issue is the lack of historical data, followed by the effect of other factors that influence MOD demand for spectrum, led by: operational requirements, advances in technology making it possible to use more spectrum, and politico-military considerations such as force interoperability.

These difficulties are in addition to some less endemic challenges with timeseries analysis, e.g. autocorrelation in the data, and the limited length of the history available in the data, relative to the decision making cycles

Requirements-based Approach

The third approach we considered was one driven by more intimate knowledge of defence requirements for spectrum, both today and in the future. This approach requires considerably more detailed analysis of demand through stakeholder discussion, and additionally requires a strong understanding of future requirements and other drivers in order to predict the economic impact of spectrum demand.

[22] "A Welfare Analysis of Spectrum Allocation Policies", Hazlett and Muñoz, AEI-Brookings Joint Center for Regulatory Studies, 2004

Whilst this method does not enable direct derivation of economic demand and supply curves in the same way that the two earlier approaches might, it does enable a more informed discussion of future demand and sensitivity to AIP, through secondary analysis of the demand data collected.

For the reasons cited above, we selected approach 3) as being the most appropriate for this work. The detailed methodology for this is described below; the results in Sections 2 and 3 are based on this model. In Section 6 we derive some additional economic outputs that are drawn from the analysis that we have carried out.

5.2 OUR APPROACH

The main focus of the economic modelling is current and future demand, with some analysis of optimisation and reuse.

The modelling starts from data gathered on the MOD's diverse demands for spectrum. From that data we are able to understand options for altering spectrum demand, and the economic implications of those options. We do this in the following steps:

- Defining each demand in detail, quantifying it, and setting out its coverage in time, space and frequencies
- Determining the potential for spectrum reuse within the MOD's diverse range of demands – and distinguishing between:
  - cases where reuse across locations and systems seems to be feasible
  - cases where reuse may be possible, but would require increased frequency optimisation, and careful and systematic spectrum management
- Deriving the overall demand for spectrum, across systems and across the country
- Determining the cost of fulfilling this demand – the charges derived from the AIP tariff.

Within this workstream, the primary focus of the economic modelling therefore is to quantify the economic impact of MOD's spectrum demand, in order that informed decisions can be made about the cost of capability provision and the appropriateness of system decisions.

5.3 UNDERSTANDING DEMAND FOR SPECTRUM

In recognition that getting accurate estimates of spectrum demand from stakeholders would be difficult without offering scenario-based context, a series of 'Demand Building Blocks' (DBBs) (so called so as not to confuse with the strategic scenarios) have been developed to demonstrate localised spectrum demand.

We believe, and precedence exists within commercial demand studies, that extrapolation from such DBBs can form a realistic estimate of consolidated demand. Additionally the vignettes will highlight exceptions; unique capabilities, locations, or equipment that is not covered by initial data capture.

The DBBs were developed around current known defence and military units and locations.

FLEET - The regular element of FLEET consists of approximately 35,000 Officers and Other Ranks, and 9 Major Surface Vessels, 26 Destroyers and Frigates, and 16

Minewarfare Vessels. There are 28 Patrol Vessels and Craft. There are 21 Fleet Support Ships (manned by the Royal Fleet Auxiliary). There are 2 Naval Operating Bases – Portsmouth and Plymouth, and three Naval Dockyards, Portsmouth, Devonport, and Rosyth. There are 14 Submarines operating from Faslane.

LAND - The regular Army element of LAND consists of approximately 75,000 Officers and Soldiers, and approximately 16,000 military vehicles fitted for/with communications. There are over 120 regular major units, of which approximately 90 are based in UK. The majority of Army units in UK are centred on three garrisons – Tidworth and Bulford, Aldershot, and Catterick. The majority of LAND based training takes place on Salisbury Plain, Stanford Training Area, Sennybridge Training, and Warcop – with major firing ranges at Bovington, and Otterburn.

AIR - The regular element of the RAF consists of approximately 41,000 Officers and Other Ranks. There are 39 Operational flying Squadrons, with 9 Main Operating Bases around the UK.

The DBBs have been kept as generic as possible to allow consolidation. We recognise that they need to be additive so that sites with multiple functions (represented by multiple vignettes of the same or differing nature) can be estimated effectively.

A full description of the DBBs is included in Appendix C.

5.4 AGGREGATING DEMAND ACROSS AT LOCATIONS

Once the DBBs have been defined and set up to support the allocation of equipment to MOD locations, the next step of the process is to derive a quantified view of demand across the UK. The main steps in this process are as follows:

- Assign each equipment item to appropriate band(s) according to its use and tuning range
- For each item of equipment, quantify the demand, i.e. the spectrum used for transmission, at a typical or "standard" site
- Use the mapping of DBBs to Locations to assign this demand to the sites that use the equipment, and scale the demand for spectrum according to usage at each site[23]
- Determine which locations are close enough to cause interference with each other, according to the nature of the equipment. Figure 5-1 and Figure 5-2 illustrate two examples; for the first of these the degree of interference is moderate, for the second it is high.
- Aggregate the amount of audible use of spectrum at each site that uses the band, and then quantify the amount of spectrum required in the band in order to meet the demand.

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[23] As an example, a large training area may need to accommodate up to six units at a time, and the volume of use at this location may be six times that of a standard site. The demand for spectrum at this site may also to be higher than at a standard site; not necessarily six times the standard demand, depending on the nature of the equipment and its modes of use.

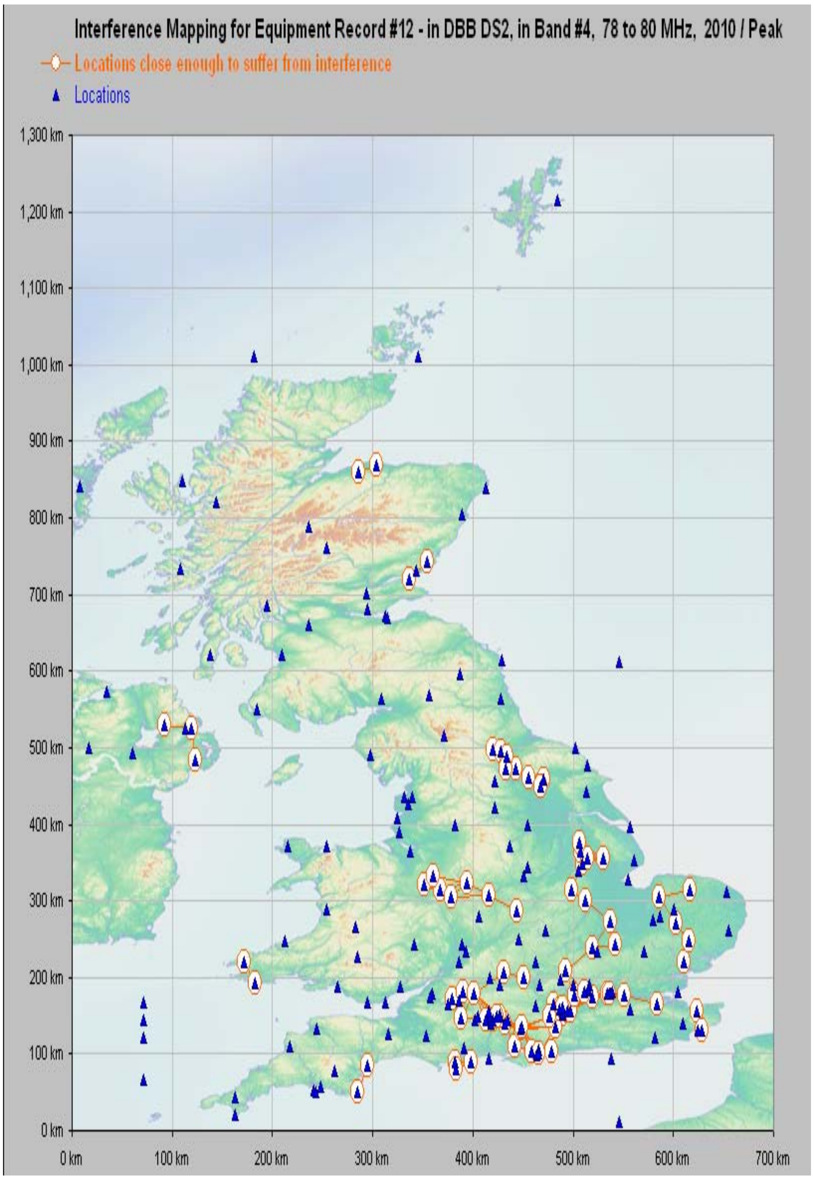

Figure 5-1: Interferences for one equipment item (moderate interference)

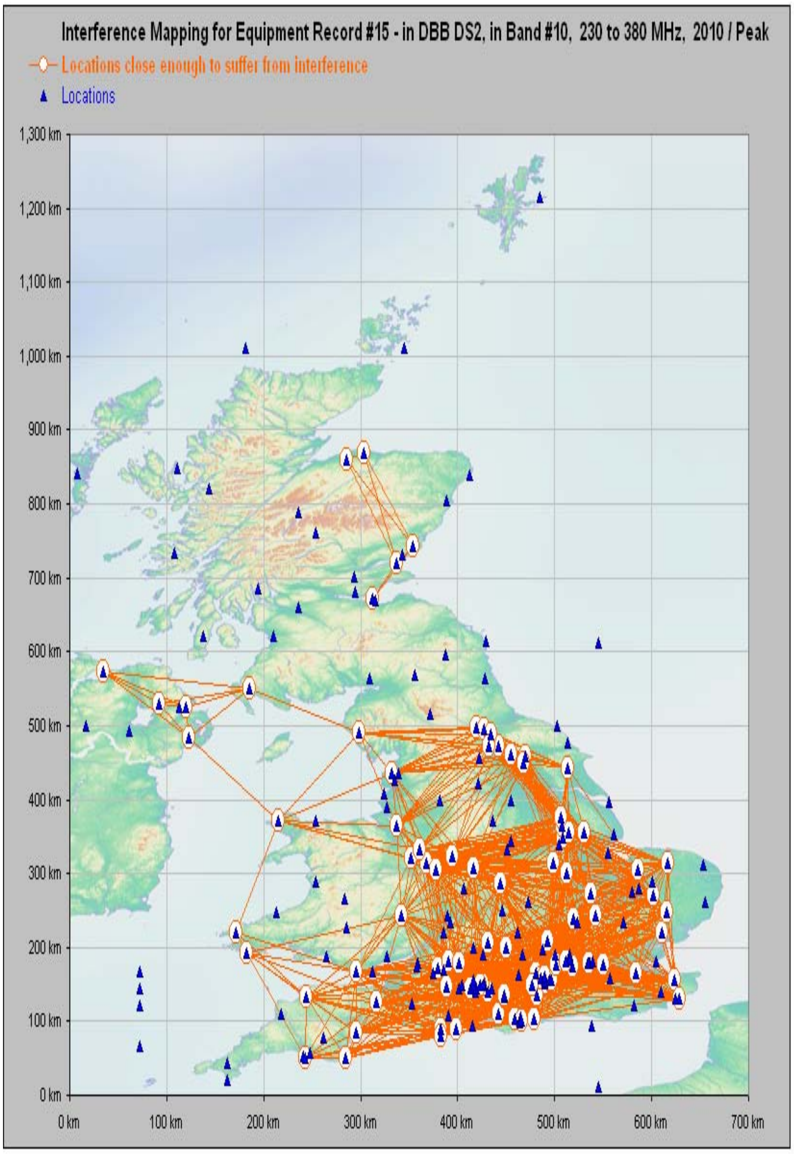

Figure 5-2: Interferences for one equipment item (high interference)

In the last of these stages, a reasonable degree of pragmatism in frequency allocation and planning has been assumed. The calculations do not assume full optimisation of the use of every piece of spectrum, but they do assume that spectrum is shared across locations, and, where beneficial, across systems, within the same band.

This view of the total MOD demand for spectrum is generated for each epoch, and is recreated for each of the various levels or elements within MOD, e.g. for each Service, or for each type of Application.

5.5 FREQUENCY RE-USE

In order to forecast Defence spectrum *demand* rather than *usage* we need to make an assumption that spectrum is used efficiently. We therefore assume that, where possible, frequencies can be re-used geographically. In practice, re-use may or may not be implemented today.

The interference model that we have assumed is that transmitters and receivers are generally omni-directional or, in the case of radars, sweep over 360 degrees (there are some specific exceptions to this such as ASACS, which have been dealt with as special cases). The criterion for possible re-use is that all interferers should individually contribute no more interference than the thermal noise floor. Where transmitters and receivers are not omni-directional, or antenna heights are significantly different from those we have assumed, actual re-use options could be significantly different.

5.6 TEMPORAL RE-USE

We have not assumed any temporal re-use in our modelling.

5.7 ANALYSIS OF SCOPE FOR REGIONAL CAPPING OF DEMAND

The maps of demand shown in Section 3 indicate that MOD demand of spectrum is not evenly spread across the UK. The results are derived from our modelling which uses a regionalised approach to determining demand for spectrum

In many bands, the pattern of MOD follows one of three or four templates:

- Regionalised, e.g. higher in South West England, lower in other regions
- Localised, in and around a small number of (generally rural) locations
- Higher in rural areas, and lower in and around most of the major conurbations
- Uniform demand across the country.

The first of these templates offers the greatest scope for MOD to assess demand for spectrum on a regionalised basis, potentially with a view to sharing, releasing, or sub-letting some of it.

The second template also offers some prospects for benefits from a regional approach, provided the MOD locations are not to widely distribute.

The third template offers some scope for considering geography; this may be regional, or it may follow a different pattern, e.g. capping routine MOD usage in and around most or all urban locations, which are likely to be of greatest interest to other prospective users of the spectrum.

For this analysis, the UK was divided into ten regions, reflecting the following priorities:

- the primary political geography of the UK, i.e. the four countries that make up the UK
- the clustering in the main patterns of MOD usage of spectrum
- boundaries should be easy to define

- boundaries should be effective at separating MOD areas of high demand from the major centres of population
- where possible, boundaries should provide some fit to the official definitions of the regions within England.

The boundaries used for the analysis are shown below in Figure 5-3.

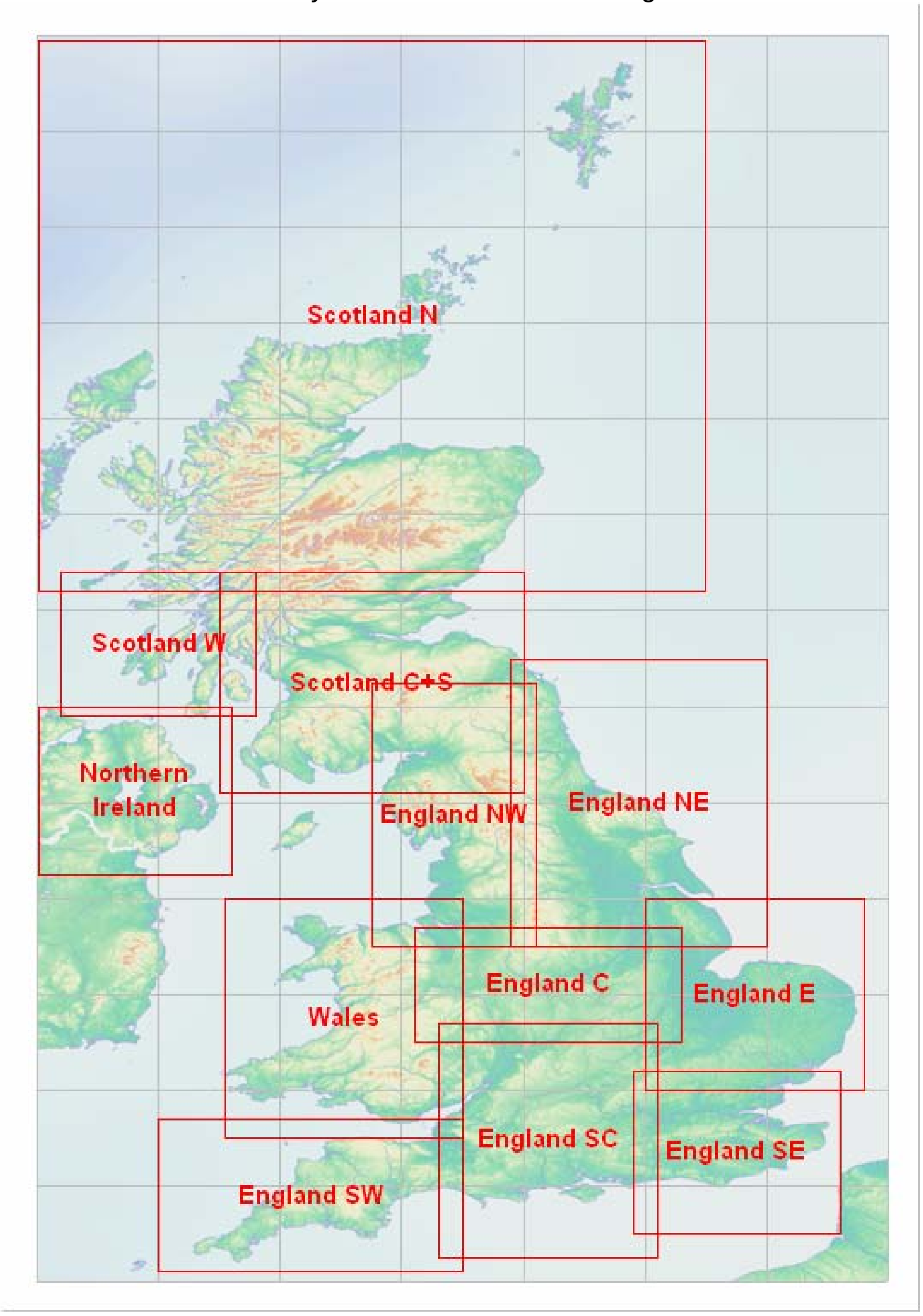

Figure 5-3: The boundaries used when assessing regional demand

5.8 MODELLING ASSUMPTIONS

5.8.1 Excess demand

In general, where a band shows excess demand, we assume that it will be managed within that band, and will not 'spill over' demand into adjacent bands. The exception to this is the 400MHz bands, which are discussed in detail in Section 3.

5.8.2 Airborne systems

We generally assume that airborne systems have ubiquitous coverage across the UK. UAVs are an exception to this since they are operated in specific locations.

5.8.3 Radars looking out to sea

For modelling purposes we assume that maritime and coastal radars looking out to sea have omni-directional coverage. This is a 'worst case' assumption.

5.8.4 The analysis is underpinned by a model of the demand for spectrum

This section gives an introduction to the model that has been developed and used to analyse the MOD demand for spectrum.

Figure 5-4 below shows the original context diagram for what the model needs to do.

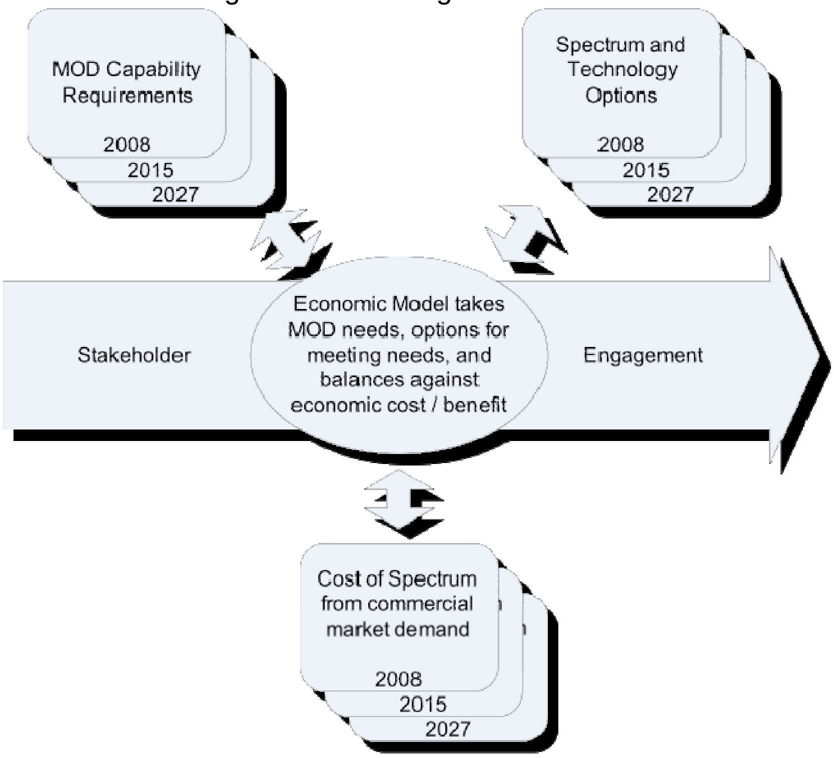

Figure 5-4: The context for the modelling approach

5.9 THE MODEL

Figure 5-5 below shows the overall structure of the model, and some of the key outputs that it produces.

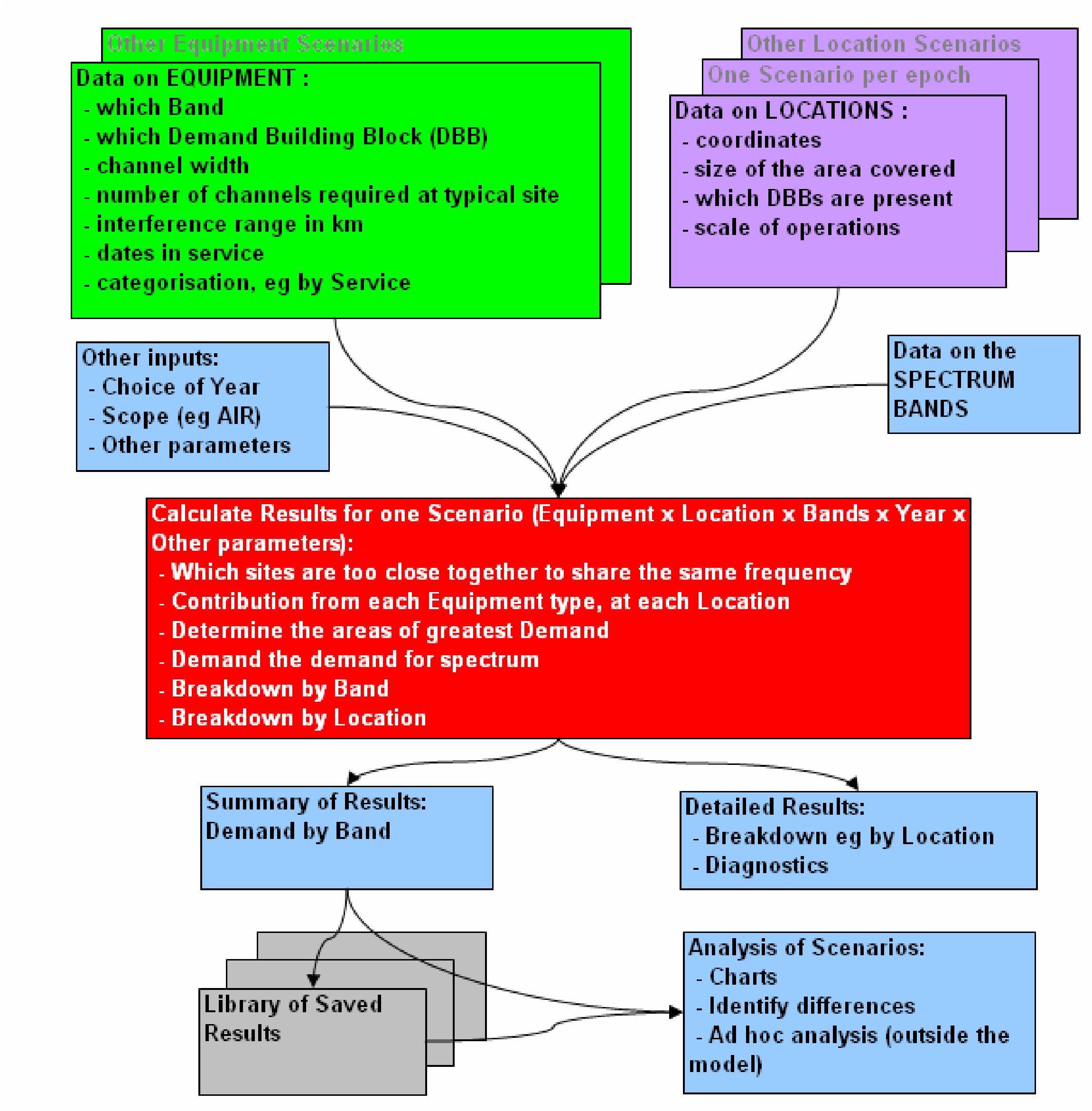

Figure 5-5: Implementation of the modelling approach

Figure 5-6 shows the navigation screen from the model. Key points are as follows:

- The colour coding of green for Equipment data, purple for Locations data, red for automated processing (macros), blue for other steps in the process, and grey for saved outputs, is carried forward into the model
- Two further shades are introduced: amber / light orange for routine sense checks and warnings, and pink, for checks for errors which should be rectified
- The boxes in the main diagram correspond to components in the model
- Arrows show the linkages between the component parts of the model

- Surrounding this main navigation diagram, there are four mini-dashboards:
  – top left (green): assessment and filtering of the data on Equipment
  – top right (purple): assessment (and any filtering) of the data on Locations
  – left centre: timestamps e.g. last recalculation, and last full run of the model
  – lower left (blue): summary of the results from the latest run.

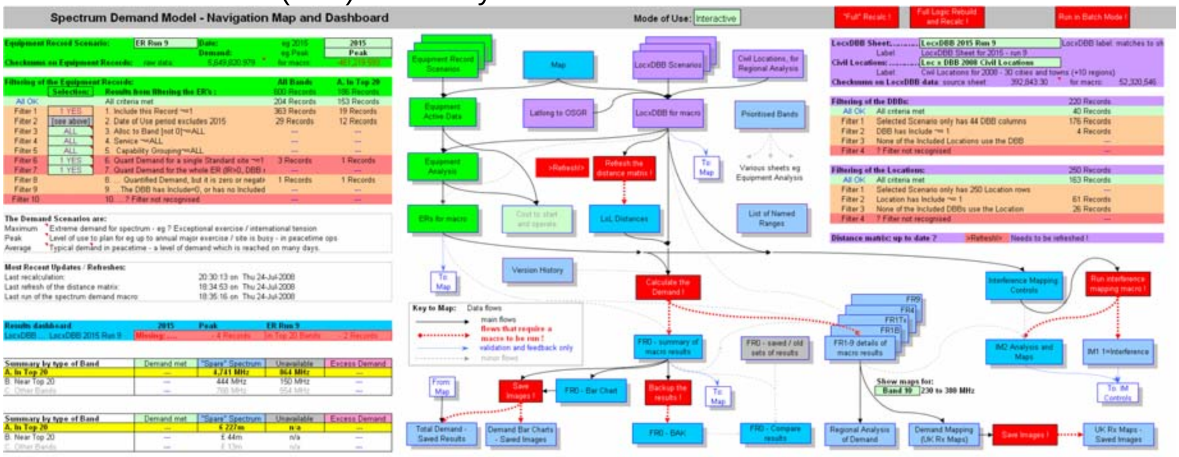

Figure 5-6: The Navigation map in the model

The model is implemented using a blend of Microsoft Excel and Visual Basic for Applications (VBA). It has no special environment requirements, i.e. it will run on a standard medium to high spec Windows PC provided that current MS Office software is installed, and VBA is enabled.

The requirements of the user depend on what they are seeking to do, for example:

- to navigate around the model: only requires general computer literacy

- to explore in depth the current solution in the model: requires familiarity with standard Excel features, e.g. the audit toolbar. In-depth exploration of the automated stages in the process is made easier if the user is familiar with the model and its documentation[24], but knowledge of VBA is not required.

The model and its documentation is delivered separately from this report.

[24] Model documentation is provided separately from this report.

6. ECONOMIC ASPECTS AND EFFECT OF PRICE ON DEMAND

6.1 THE EFFECT OF PRICE ON DEMAND FOR DEFENCE SPECTRUM

As discussed elsewhere in this report, we have developed a model enabling MOD to explore the relationships between systems that generate demands for spectrum, the total demand for spectrum, and the economic and financial impact of those demands in spectrum cost.

In addition to this, we have reviewed key selected systems which occupy particularly valuable tranches of spectrum, to understand how demand for spectrum *for those systems* may vary with economic factors, particularly price. These econometric aspects are explored in this section. Figure 6-1 shows the split between the economic and econometric elements of the modelling.

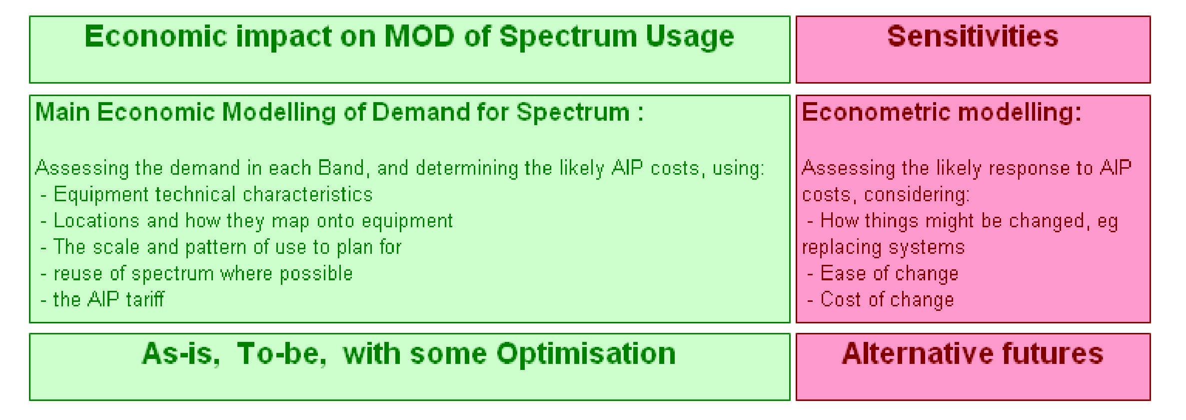

Figure 6-1: Scope of the main economic model and of the econometric modelling

In this econometric analysis we assess potential trade-offs between spectrum demand and AIP tariff, and offer some conclusions on how MOD demand for spectrum is likely to be affected by AIP and the options that should be considered.

Insights from this economic/econometric analysis are outlined at the end of this section.

6.2 ISSUES THAT SHAPE THE ECONOMETRIC MODELLING OF DEMAND

We start by outlining the approach that would be taken in the commercial world if exploring alternative futures, then consider how it needs to be adapted for the military world, and define the way forward.

Firstly we should make the distinction between the theoretical/ideal case of a ***perfect market***, and the wider body of theory and knowledge in economics and decision analysis, which includes coverage of discrete / lumpy demand. It is clearly not practical to model military demand for spectrum as a perfect market, and the approach must be designed and implemented in a way that reflects MOD's real issues such as lumpy demand (granularity) and the limited relevance of "revenue" in the military domain.

6.2.1 In the commercial world, there is a clear approach: revenue minus costs

The typical approach to economic modelling in the commercial world would focus on the value of the business (or project): the discounted sum of future expected revenue minus costs. This would then be used to explore the effects of altering the amount and type of spectrum. For example, in a cellular mobile network:

- Reducing the amount of spectrum available would increase the number of sites needed in areas where demand density is high
- Shifting the radio network from lower frequencies to higher ones would mean that more sites were needed for coverage
- Having less fixed-link spectrum would mean less capacity for backhaul – potentially complicating the network architecture, adding fixed-link sites, and/or driving some substitution from wireless to fixed.

In each case, the overall method is similar:

- Determine the real-world context for the decision, i.e. in what scenario are we valuing the spectrum
- Factor that real-world scenario into the model
- Derive a value
- Repeat the process for other alternative scenarios
- Aggregate the results across scenarios to derive an overall likely value for the spectrum and a relationship between price and demand, together with an understanding of the major sensitivities and risks.

The value of the marginal unit of spectrum is then the change in the NPV of the business from holding or foregoing that marginal unit.

In practice, there are two important considerations which carry across to the military case:

- The valuations and the valuation methods are different for each band. There is no "generic" method to cover valuation for a "generic" band: *each band, and each item of equipment, needs to be considered in the light of the factors that affect it*.
- In most cases, the analysis would recognise that there is uncertainty, and conclude by *deriving a range of valuations in each band, rather than point estimates*. The upper end defines the walk-away price; the lower end signals a definite retention or purchase. Between these extremes, there is uncertainty and, especially near the middle of the range, there are grounds for retaining the status quo, because the situation may change over time: a "promising" option may become "compelling", or it may become a non-starter.

6.2.2 Defence spectrum demand is different in nature to commercial demand

Military spectrum is a vital input in the production of systems that enable military capability. It is distinguished from other applications of spectrum in that:

- Historically, military spectrum has been free of charge to the user, and its cost has not been a constraint
- Demand for spectrum is often in large discrete units and is tied to a system which is essential for some aspect of military capability
- Whilst capabilities can be discussed, any negotiation of them is not simply a matter of economics, and is well outside the scope of this study
- Often, the demand for a capability is insensitive to the price of the spectrum.

Other specific issues include: timescales inherent in deploying and using such large systems, the way in which spectrum is shared both within MOD and with commercial users, and the way in which spectrum has historically been 'owned' within MOD.

Issue 1: Time lags are a major factor

For MOD, there are long time lags in the system, due to the large and diverse base of installed equipment with long asset lives. Demand for spectrum is not particularly responsive to price in the short term.

These time lags are further extended by long procurement cycles and a typical asset life of 20-30 years.

Issue 2: Ownership is diffuse, and spectrum is not at the forefront of owners' minds

For most equipment, there is no single stakeholder holding the collective MOD view of that system. It is shared between operating units, IPTs, DECs, and others. Stakeholders are concerned with the practical aspects of the capability of the systems. For other aspects, including demand for spectrum, they are as a rule only aware of the most fundamental characteristics.

Issue 3: Total demand depends on the interactions between systems and users

Even in the case where the requirement for one system or capability has been converted into a demand for spectrum, there is a further complication: that different systems and capabilities may interact in their demand for spectrum, depending on where they are deployed, how many users there are, which bands they are in, how far their signals propagate, and other characteristics.

The net effect of this is that:

- In some cases, removing a single system or reducing the scale of its deployment and use may have no impact on spectrum demand, because the spectrum is used extensively elsewhere.
- In other cases, it may be possible to increase the demand from a system, or to add entire new systems, without increasing the demand for spectrum.

Issue 4: The culture is not geared to exploring these issues

In MOD there are strong drivers to favour retaining the status quo rather than exploring hypothetical alternatives:

- Reasoning behind existing solutions is not always readily accessed; they may include compiled and/or classified knowledge
- If a new solution does not function as specified, or if the specification omits important aspects, then capability is lost – potentially with serious consequences such as expensive rework or even lives being lost in conflict. Whilst it may be argued that compromises may be possible during training, the MOD tenet of 'train as we fight' comes into play here, with concerns being that if training is not as realistic as possible, errors will occur on the battlefield.

Issue 5: Individual bands are shared between multiple systems, applications and capabilities

Because MOD has regulated its own access to spectrum for many years, it has frequently shared spectrum use in a way that doesn't happen with commercial ownership of allocations. This makes it very difficult to place a value on usage of a specific band.

- Bands are shared between multiple systems and applications, each of which is likely to place a different value on its demand for that band
- Some of these systems could be moved to adjacent bands at relatively low cost, whilst others may be impossible to move in practice.

6.2.3 The econometric analysis therefore needs to focus on the systems where AIP may make a difference

Taken together, the five issues discussed above indicate that it is not practical to model the economics of the military demand for spectrum in its entirety.

Instead, it still seems desirable to explore the economics of military demand for spectrum, focusing on systems where:

- There is significant spectrum value at stake, as measured by AIP values and MHz
- The prospects for analysing the alternatives seem reasonable
- Preferably, there appears that there may be some sort of relationship between the AIP tariff and the MOD demand for spectrum.

6.2.4 Our approach recognises the differences between commercial and defence spectrum demand

This Defence Demand Study can apply the same approach as in the commercial world, but with adaptations for the military data and context – notably that 'revenue' is not material, and that the stakeholders are different and diverse.

The differences for this study are as follows:

- The revenue side is replaced by *capability*.

- The focus is on how MOD can most efficiently use spectrum to deliver the same capabilities. This is essentially about taking a pragmatic view of the demand that MOD needs to plan for, assessing and improving frequency reuse, eliminating waste where possible, and assessing the scope for partial sharing or release. Optimising the response to changes in price of resources such as spectrum, which is scarce but more or less essential, is worthwhile, but it is not the main focus.

- From our work in this study, and particularly from our discussions with stakeholders, it is clear that the Defence demand / supply elasticity "curves" are overwhelmingly discrete rather than continuous.

- In assessing the econometric aspects, the study therefore needs to focus on alternatives that involve matching or exceeding the declared required military capability, which is taken to be the capability currently delivered, such as:
  - Replacing or upgrading equipment that moves the spectrum requirement to a different band
  - Considering and seeking increased reuse of spectrum across MOD sites,
  - Where practical, merging similar needs into one common system or band, or moving from bespoke to commercial systems to deliver capability.

- There is a potential risk of limiting future military capability; releasing spectrum which is needed 10 or 15 years later, e.g. for reasons related to specific emergent threats. In these cases, MOD may wish to retain rights to some of the released UK spectrum, e.g. to reclaim some or all of rights, with suitable notice and perhaps to an agreed pricing mechanism. This area of options analysis may become important when and if MOD starts to think about releasing or sub-letting spectrum.

- The process of considering alternative ways to deliver existing capability is difficult for any subset of the stakeholder community. So, efforts to explore alternatives must focus on spectrum with significant AIP, where there are reasonable prospects for reducing demand by altering or replacing equipment or improving the reuse of spectrum.

- Rather than resembling a perfect market, MOD demand for spectrum (with capability requirements fixed) is akin to the demand that a business services company has for staff, after they have signed up a large customer for a fixed specification, non-cancellable service contract. The company could try to make do with fewer staff, but there is a tradeoff between cost, quality, scope, and risk. However, if the cost of the staff doubles, their demand for them is not going to vanish. There will be some stress, and some attempts at tinkering, but *once the contract for the service is signed*, demand for the staff is highly inelastic to price.

6.3 OUR APPROACH

The approach taken was as follows:

- Within the 20 bands covered by this study, examine the Equipment items focusing on those falling into the Cave Bands of greatest interest and AIP[25]. These Bands cover approx 80% of the AIP is scope, and they are prioritised to reflect market interest / their likely value, ease of release, etc.
- Identify which Equipment items have potential for econometric modelling
- For these Equipment Items, the range of alternatives explored was as follows, homing in on the most promising alternatives as they emerged:
- Determine whether there may be potential to scale back allocations where demand has declined, or is really outside the UK, or has been set to cover a particularly a scenario of unusually high demand.
- Explore like-for-like replacements of capability (e.g. new equipment for old) using the same UK spectrum, but less of it. Cost estimation should cover both capex and opex and should ideally be risk-adjusted – i.e. for the risks that new solution might not work in practice, and the project costs might have to be written off - as well as recognising the side-benefits, e.g. if new equipment has lower running costs and longer asset life.
- Explore potential for replacements in different bands, typically with lower AIP.
- Explore the potential to improve frequency reuse and sharing across MOD, factoring in major costs of change and noting any consequences for longer term capability.
- Assess what is the best alternative to and the cost of supplying the same military capability with less spectrum in a particular band; ideally, doing this in increments, e.g. 20% less, 50% less, 80% less.
- Explore areas where capabilities are driving appetite for more UK spectrum, focusing on known areas where demand is believed to be growing. For example, for HCDR / tactical mesh networks:
  - what can be done with current UK allocation
  - what would 2x or 5x the UK spectrum enable, and how could that be delivered with existing spectrum; what would it cost
  - what other effects would there be – e.g. making it possible to end UK use of other systems or bands that are used to deliver the same kind of capability

[25] There is an element of judgement here regarding which capabilities and systems should be covered. Our assessment has covered the most meaningful example of variable spectrum demand for the majority of the 20 priority spectrum bands, with an emphasis on the bands with the greatest AIP charges, whilst ensuring a reasonable representation from different parts of MOD.

In the bands analysed, it may be possible to find other systems with a response to price, but in other cases, likely the majority, the other demands in the band will exhibit little sensitivity to AIP.

- For cases where capabilities are driving demand growth, the approach would need to compare alternative ways to get the extra capability – e.g. investing in equipment or spectrum, or deferring and buying next generation equipment – to derive the right comparisons.
- Finally, explore the potential for partial release or sub-lets, e.g. for metropolitan areas of high civilian demand where MOD usage is limited and distant.

For many systems, it is difficult to explore most of the alternatives. In those cases we have focused on asking experts to explore only aspects that make the most sense, and in many case we have made some very rough placeholder estimates of how the alternatives might cost out.

For all of these considerations, the assessments made here represent the opinions of stakeholders and/or experts, rather than fact. It would be hazardous to take the reasoning outlined here and assume that these systems could be altered to the cost, timescales, and risks as described below. A different expert or stakeholder might come to different conclusions for individual systems, but we would expect the overall conclusions outlined in in the following sections to be broadly resilient.

We should stress here that the process here is intended to give some insight into the econometrics and to draw broad conclusions, not to present a rigorous business case for individual items of equipment.

6.4 INSIGHTS FROM ASSESSING INDIVIDUAL EQUIPMENT ITEMS

Table 6-1 below indicates which bands were covered by this assessment.

Band Edges (MHz)		Net width MHz)	AIP per MHz £k)	New Total AIP (£)	Econometric Analysis
3100	3400	300.0	Medium	£36m	Included
2700	3100	280.0	High	£67m	Included
3400	3600	120.0	Medium	£14m	Included
230	380	150.0	High	£30m	Included
2310	2390	80.0	High	£19m	Included
4400	5000	600.0	Low	£11m	Included
410	430	16.0	Very High	£6m	Part Included
430	450	20.0	Very High	£8m	Part Included
5650	5850	100.0	Low	£2m	Part Included
380	400	10.0	High	£2m	Part Included
5300	5650	350.0	Low	£6m	Included
401.5	406.1	6.0	Very High	£2m	Part Included
8025	8400	375.0	Low	£5m	-
8500	8750	250.0	Low	£3m	-
9500	10125	625.0	Low	£5m	-
14620	15230	610.0	Low	£5m	-
7250	7400	150.0	Low	£2m	-
9000	9500	250.0	Low	£2m	-
13250	13400	150.0	Low	£1m	-
13400	14000	300.0	Low	£2m	-
14620	15230	610.0	Low	£5m	-
Breakdown of AIP:				£223m	
Included				£173m	78%
Part Included				£20m	9%
-				£30m	13%

Table 6-1: The scope of the econometric analysis

The template for these assessments is as follows:

- *Existing solution*
- *Quick wins* / changes in the pipeline: Any changes easy to achieve / likely to happen, these form the baseline for the evaluation in remaining steps in the process.
- *Options*: How could the current capability be delivered with a different solution – new equipment, retuning, etc – and exploring what would be done if the allocation were to change. This focuses on the most promising option(s).
- *Tradeoffs*: Weighing each of the *Options* against the *Existing Solution* / *Quick Wins*.
- *Decisions*: Selecting the most attractive option.
- *Econometric results and insights*: Conclusions from assessing this equipment.

In Table 6-2 below we show our initial assessment of the number of systems which we considered likely to be sensitivity to price, and which were then taken forward for analysis. Details of individual systems are covered in Appendix H [Protectively Marked].

Assessment: is Spectrum Demand likely to be sensitive to AIP?	**Number of Equipment records[26]**	**Next steps for econometric analysis**
Potentially sensitive to AIP	15	Included
Unlikely to be sensitive to AIP	57	Excluded
Spectrum demand is small, not worth assessing	16	Excluded
Difficult to assess sensitivity and in top 20 bands assessed	75	Excluded
Difficult to assess sensitivity but not in top 20 bands assessed	102	Excluded

Table 6-2: Initial filtering of systems for econometric analysis of sensitivity to AIP tariff

In the following sections 6.4.1 to 6.4.9 we consider in detail those systems that we regard as ‘Potentially sensitive to AIP’.

[26] For most systems, that have one aggregate set of demand for spectrum, each system accounts for one Equipment Record. For those systems with demand in more than one band, each band is counted as one Equipment Record. The number of Equipment Records is not related to the scale of deployment or usage.

6.4.1 Price elasticity of spectrum demand – Voice and Data Links Case 1.1: PMR

Existing solution

Frequency:	230-380MHz band plus 410-430MHz, 430-450MHz, and others
Range:	Short range, so limited interference between sites
Site allocation:	Present at many (100+) sites, with allocations found in 4 or 5 bands for these; a 'standard site' needs 25-100kHz in each of the bands, a major location may need several times as much. This might overstate local demand in some cases, but should be reasonable for assessing national demand
Spectrum demand:	3MHz
AIP:	£1.2M per annum (£400k per MHz).

Quick wins / changes already in the pipeline

None identified, although arguably the plan outline under (C) below, if practical, might count as a quick win.

Options

Standardise on one band, fit the demand into about 1MHz rather than 3MHz.

Replace over 5 years, as and when needs replacing: minimal / no additional cost.

Assuming £250 per set, at 2,000 sets the cost is £500k, i.e. less than 6 months' AIP.

Tradeoffs

Assuming say 2,000 handset and a reduction in demand for spectrum of 2MHz.

Replacement 100% in year 1 would cost £250 x 2000 = £500k.

AIP saving: 2MHz x £400k pa = £800k pa. i.e. at this price there is a case for pressing ahead rather than the 5 year rolling replacement programme.

Replacement with pure COTS systems would cost the same or less and save the whole 3MHz (£1.2m pa).

Existing spectrum costs: £600 per handset per year. Setting aside considerations of capability, a COTS solution or mobile cellular solution would be lower cost, and may have additional benefits e.g. availability of spares, outsourced solution.

Decisions

Investigate scope for COTS or similar solutions - do they meet MOD requirements, what if any adaptations would be required, e.g. would the equipment work on expedition, or would there be a requirement for dual kit (MOD kit on expedition, leave the UK site kit on the UK site). Include any benefits too.

Assess costs / benefits of standardising PMR solution in one band over 6-12 months.

Assess scope for standardising in one band, e.g. in rolling 1-5 year programme.

If none of these are feasible then retain the status quo.

Econometric results and conclusions

Spectrum Demand is very sensitive to feasibility of change / any loss of capability.

Spectrum Demand is potentially sensitive to perceived cost, risk, and benefits of changes - reduction might be 2 - 3MHz depending on costs / risks / benefits of changes.

Spectrum Demand is quite insensitive to AIP over a wide range of AIP values - at £400k / MHz / year the case for change is strong. Provided that AIP is more than about £40k per MHz pa, a reduction in demand seems likely. Further increases in AIP would not further reduce MOD demand for spectrum, because the commercial case for change appears strong.

6.4.2 Price elasticity of spectrum demand – Voice and Data Links Case 1.2: Other

Two other Communications systems may offer prospects for a response to the AIP tariff, providing there are no major constraints from interoperability requirements.

- Bowman HCDR. 4MHz channels in the 230-380MHz band. It appears likely that its demand for spectrum could expand substantially beyond the figures (tens of MHz) modelled. However at present its usage is capped by limited spectrum availability. This system would be a candidate to take up any spare spectrum in the band, and might therefore exhibit some sensitivity to price, because the decision is about adding additional capacity and hence capability, rather than changing what is already operational.
- Air to Air comms. In the 230-380MHz band there is one system with a recorded demand for 140 channels at 0.025 MHz each – prompting the question of whether this demand would reduce if AIP were higher. However, this is more likely to be a case of either needing these channels, but only rarely, or of the demand being amenable to capping, largely insensitive to AIP because the cost impact of the change would be small relative to the AIP, but sensitive to the perceptions of the impact on capability and risk.

6.4.3 Price elasticity of spectrum demand – Navigational Aids Case 2.1: C130 Hercules

Existing solution

Frequency:	3400-3600MHz band
Range:	Approximately 25km interference range
Site allocation:	25 units installed on aircraft. It is used in the UK for exercises in the UK - a few hours per month, interfering over only a small (albeit varying) area.
Spectrum demand:	56MHz (14 channels of 4MHz)
AIP:	£7 M per annum (£120k per MHz)

Quick wins / changes in the pipeline

The assessment of demand at 14 Channels is perhaps generous for UK use. 10 channels may suffice, in which case there would be a reduction of AIP charge from £7m to £5m pa.

Options

Approach 1: Replace with equipment using a band with much lower AIP.

- Approx £1m each for new equipment, total £25m
- New equipment would probably be an improvement on the old, and would still work on outside the UK.
- New equipment could be rolled out to individual aircraft – there is no need to synchronise the installation or to run both systems in parallel.

Approach 2: upgrade existing equipment, e.g. time domain sharing.

- Costing perhaps £250k per fit, total £6m
- Might make it possible to reduce demand, from 10 channels to 2-4.

Approach 3: move equipment to the low end of its Tunable range, below 3400MHz.

- The lower band has a similar AIP, so any benefits would depend on securing some shared spectrum at little or no incremental cost to MOD.
- The cost of change would be modest.

For this item, there is a need to consider risks:

- With approach 1 or 2, there may be additional costs, e.g. refresh of airworthiness certificate
- Approach 2 is believed to be workable but needs assessment - otherwise it may bring risks to capability.

Costs

Costs, including allowance for risk, and the effect on AIP charges, would then be:

Approach 1: New equipment: £40m including uplift for risk.

- The effect on AIP would be to move the equipment to a band with much lower AIP - reducing AIP from £5m to say £1m - saving £4m pa

Approach 2: Upgrade - £10m including uplift for risk.

- There would be a small cost to confirm feasibility, and assuming positive, reduction of AIP from £5m to say £2m, saving £3m pa

Approach 3: Costs not established; we adopt a placeholder estimate of £5m

- Small cost to confirm feasibility and costs; if favourable, reduction of AIP of up to £5m, assuming a suitable sharing partner can be found in the lower band.

Tradeoffs

Approach 1	Costs £40m, AIP saving: £4m, NPV ~ neutral at AIP tariff of £120k.
Approach 2	Upgrade £10m, AIP saving: £3m: NPV is very positive at AIP tariff of £120k, project would be justified at any AIP over £40k.
Approach 3	Costs of £5m, AIP savings of up to £5m, NPV very positive at AIP tariff of £120k, project is justified at any AIP over £15k.

If considering foregoing UK use: Taking a placeholder estimate of UK usage of 50hr/year and comparing with £5m of AIP, amounts to a spectrum cost of £100,000 per hour of use.

Decisions

- We would perhaps revise allocation downwards from 14 to 10, reducing demand by 16MHz, ie by 30% of the equipment's demand in this band. This reduced level of demand - 10 channels, ie 40MHz – would then be the new baseline for comparisons.
- Explore approach 3. If this delivers savings of most or all of AIP, then adopt (requires AIP greater than about £15k), reducing demand by 40MHz - 100% of the equipment's spectrum demand in this band, or about 15% over the two bands 3100-3600MHz .

Otherwise ...

- Explore approach 2. If in line with analysis above then adopt it (requires AIP >~£40k). reducing demand by 24-32MHz - 60%-80% of equipment's demand in this band.

Otherwise ...

- Explore approach 1. If in line with analysis as above then is marginal. It requires AIP >~£100k-£150k to be attractive, so there would be some response to AIP pricing.

Otherwise…

- Consider the scope for a further squeeze on the number of channels – perhaps that 14 can be reduced below 10, to 8 or even 6. However this is a judgement involving a tradeoff of capability and the assessed level of demand – so it would be misleading to treat this as a sensitivity to the price of spectrum.

Econometric results and conclusions

- Demand is very sensitive to the feasibility of proposed changes, which needs to be assessed with some rigour (effort, time, and cost) before spectrum can be released.
- There is a lag in the system. It seems likely that demand can be reduced over a 2-5 year time scale, but an immediate reduction in demand (beyond the new baseline of 40MHz) is more difficult, even a reduction to 24MHz or 32MHz may bring risks to capability.
- Demand can have some sensitivity to AIP:
  - in the case where approaches 2 and 3 are not practical, but approach 1 is feasible. In this case, demand is equally sensitive to: AIP, costs of change, risk of escalation in costs of change (and, strictly, the risks of AIP declining, although this is not perceived as a major risk.)
  - in the case where none of the approaches are viable, and where there is no prospect of sub-letting the spectrum on terms acceptable to MOD, there may be a judgement squeeze on demand, at mid to high AIP.

But, in all other cases, demand is insensitive to increases in AIP, and has only limited sensitivity to reductions in AIP.

6.4.4 Price elasticity of spectrum demand – Defence and Weapons Radars Case 3.1: Banshee

Existing solution

Frequency:	3100-3400MHz band
Range:	Approx. interference range is ~150km
Site Allocation:	Single remote site in Scotland.
Spectrum Demand:	15MHz
AIP:	£1.8M per annum (£120k per MHz)

Quick wins / changes in the pipeline

None.

Options

Is there scope to share spectrum? Perhaps to share with other aerial target systems used at the same location, on the assumption that they would not fly at the same time; or with systems used in England/Wales, or with a geographical sub-let to another party.

Relocation was considered briefly, but there is no obvious better venue.

Tradeoffs

At present there is an operational cost of £2m pa, it is believed likely that this cost could be justified, but might prove to be a factor in the assessment.

Decisions

If this is the only use of these frequencies, then sub-let over the rest of the UK, making the frequencies available for 99%+ of the UK population (95%+ of the Scotland population, including all of the cities, 100% elsewhere).

Otherwise … retaining the status quo seems the best option.

Econometric results and conclusions

Demand is potentially sensitive to AIP versus perceived value of the capability: AIP prompts at least some consideration of whether the cost would be better allocated elsewhere.

Geographical distribution of demand makes it feasible to share with other MOD or non-MOD users.

6.4.5 Price elasticity of spectrum demand – Defence and Weapons Radars Case 3.2: Watchman

Existing solution

Frequency:	2700-3100MHz band
Range:	Approx. interference range is ~220km
Site Allocation:	Single remote site in Scotland.
Spectrum Demand:	3.5MHz used at each location. National demand is about 25 times that of one standard site, ie of the order of 100MHz but somewhat dependent on detailed frequency planning
AIP:	£24M per annum (£240k per MHz) if charged in full, but shared band with MOD paying approx. 70% of band costs

Quick wins / changes in the pipeline

No quick wins but some complications e.g. from wind farms affecting operations.

Replace with similar capability

Consolidation - nearby sites can share / network of sites rather than having uncoordinated use.

Tradeoffs

Cost of consolidation and frequency planning estimated at approximately £30m.

This would reduce demand for spectrum by 30-40%, subject to proper assessment, saving £8m pa of AIP.

Decisions

Investigate scope for consolidation, and, assuming costs and benefits are in line with those projected, implement it (requires AIP of about £100-200k/MHz / year to break even)

Otherwise its probably retain the status quo for operations

There may be scope for negotiation regarding the allocation of AIP / band sharing.

Econometric results and conclusions

Demand is sensitive to AIP versus perceived cost of change.

Demand is also sensitive to the arrangements for sharing AIP with other users - a higher AIP may prompt renegotiation of band sharing commercial arrangements.

6.4.6 Price elasticity of spectrum demand – Defence and Weapons Radars Case 3.3: T101 Radar

Existing solution

Frequency:	2700-3100MHz band
Range:	Approx. interference range is ~220km
Site Allocation:	Single remote site in Scotland.
Spectrum Demand:	30MHz used at each of two sites. National demand ~60MHz.
AIP:	£14M per annum (£240k per MHz)

Quick wins / changes in the pipeline

None.

Options

Synchronise the sites, reducing the demand for spectrum by (at the most) 50%.

Reduce the number of channels … but this reduces the resolution (and resilience) of the system - not prudent.

Tradeoffs

Option C1 would save up to £7m pa of AIP and is believed to be feasible. It would be viable, barring unexpectedly high costs.

Option C2 is ruled out as too detrimental to capability.

Decisions

Investigate scope for synchronisation, and assuming no detriment to capability, and that costs and benefits are in line with those projected, implement it. Not sensitive to AIP - so long as AIP is at least approx £10k/MHz / year.

Otherwise retain the status quo.

Econometric results and conclusions

Demand is sensitive to feasibility of change.

Demand is potentially sensitive to perceived cost of change.

Demand is insensitive to AIP over a wide range of AIP values.

6.4.7 Price elasticity of spectrum demand – Defence and Weapons Radars Case 3.4: T93/T102 Radar

Existing solution

Frequency:	The T102 is a new radar being introduced in 2009, in the 2700-3100MHz band, replacing T93 in 3100-3400MHz, and reducing the demand for spectrum considerably –from 255MHz to 63MHz
Range:	Approx. interference range is just under 1,000km
Site Allocation:	Two sites.
Spectrum Demand:	30MHz used at each of two sites. National demand ~60MHz.
AIP:	£15M per annum (£240k per MHz) for T102 when in service

Quick wins / changes in the pipeline

This impending replacement will deliver a large reduction in spectrum demand and AIP, compared with the old system.

Options

There is some potential to synchronise these sites – this might reduce spectrum demand from the system by 60%-80%, eg by a further 40MHz, particularly if the synchronisation extends to cover the T101 radar in the same band.

Tradeoffs

The quick wins are set to reduce the spectrum demand from this system by 75%.

Further reductions in T102 demand for spectrum would potentially give rise to cost savings of the order of £9m to £12m pa but in practice the effect on total MOD demand is much less than at first sight, because the spectrum is shared with other systems, in a congested band – it is likely that less than half of the reduction in the system's spectrum demand would translate into a reduction in MOD demand.

Decisions

Investigate scope for synchronisation, and assuming no detriment to capability, and that costs and benefits are in line with those projected, implement it. Not sensitive to AIP - assuming that AIP is at least approx £10k/MHz / year.

Otherwise retain the status quo.

Econometric results and conclusions

Large reduction in the demand for spectrum is foreseen, but this is already in the pipeline.

Demand is sensitive to feasibility of change and any detrimental impact on capability.

Demand potentially sensitive to a large increase in the perceived cost of change.

Demand is insensitive to AIP over a wide range of AIP values.

6.4.8 Price elasticity of spectrum demand – Defence and Weapons Radars Other Candidates

Sampson Radar / LRR / T1008: There is some scope to flex the demand or share assignments within the UK. The modelled assignments are quite modest, relative to the equipment's appetite for spectrum: in a more hostile situation the equipment can use considerably more.

Range safety radar: Stated demand is perhaps overstated – a lower figure would probably be acceptable. However this is sensitive to risk and feasibility, not to particularly sensitive to AIP.

EW System: This system operates in the 5650-5850MHz band, where the AIP is low. Its projected demand for spectrum may be overstated; if this were confirmed, then a lot of it could be freed up e.g. to make room for radar and landing systems at 3GHz to migrate to this (much cheaper) band.

6.4.9 Price elasticity of spectrum demand – Other Case 4.1: Reaper (Used for UAVs)

Existing solution

Frequency:	2310MHz – 2390MHz band
Range:	Approx. interference range is ~150km
Site Allocation:	One remote location.
Spectrum Demand:	20MHz.
AIP:	£5M per annum (£240k per MHz)

Quick wins / changes in the pipeline

No quick wins identified, but this is an area where MOD demand for spectrum may grow.

Options

Approach 1: Move the system above 5GHz, or add RF interfaces above 5GHz. This seems to be financially viable at the current AIP cost of £5m pa.

Approach 2: Smaller channels of e.g. 4MHz could be adopted, but the system would lose capacity, and this would impact on capability.

Approach 3: Regional sharing appears feasible. Scotland and the SE of England appear to be relatively easy to release; for other regions, there are varying degrees of tradeoff between capability/risk and cost.

Consideration was given to channel sharing – e.g. temporal sharing with other UAV systems (Watchkeeper) - and to coding schema, but these were ruled out as not feasible.

Tradeoffs

For Approach 1, Cost of change estimated as ~ one year's AIP, subject to quite a wide a margin of error on either side but it appears that at the current AIP, change is justified.

Approach 2 is ruled out as too detrimental to capability.

For Approach 3: AIP is £5m pa for the UK, a regional release would reduce this to somewhere in the range £1m-£4m pa. This would need to be assessed properly, but costs of implementing the change would be likely to be minimal.

Decisions

Investigate Approach 1 and implement if feasible, low risk, and not too expensive.

If Approach 3 turns out to be infeasible, expensive or risky, then examine Approach 1.

Econometric results and insights

Assuming that Approach 1 is viable, demand for spectrum would have some sensitivity to AIP, with a breakeven AIP of perhaps £50k: at the current AIP, of £240k, demand would be likely to move to a higher band.

There is a reasonable case for regional sharing or release, this is very insensitive to AIP but sensitive to risk.

6.5 ESTIMATING AN ELASTICITY FOR THE RELATIONSHIP BETWEEN THE AIP TARIFF AND MOD DEMAND FOR SPECTRUM

Taking the combined effect of the sensitivity to AIP tariff of all of the foregoing examples, we can derive some very approximate estimates of how the total MoD demand for spectrum would vary, as the AIP tariff is varied; from the current level, to twice, five, or ten times the current level, or down to a fraction of the current level.

Figure 6-2 below shows the data points derived from the empirical assessment of the examples in section 5.4, and the line of best fit, postulating a constant elasticity relationship between MoD demand for spectrum, and the AIP tariff, ie of the form

*MoD demand for spectrum (Band) = Baseline_demand (Band) * (AIP_tariff_scale_factor (Band) ^E)*

Where E is the elasticity of demand to the AIP tariff.

Figure 6-2 confirms the common-sense view, that the AIP tariff may have some impact on MOD demand for spectrum but the elasticity is low – the observed value of -0.01 is close to zero, so a large change in AIP has quite a small impact on demand for spectrum.

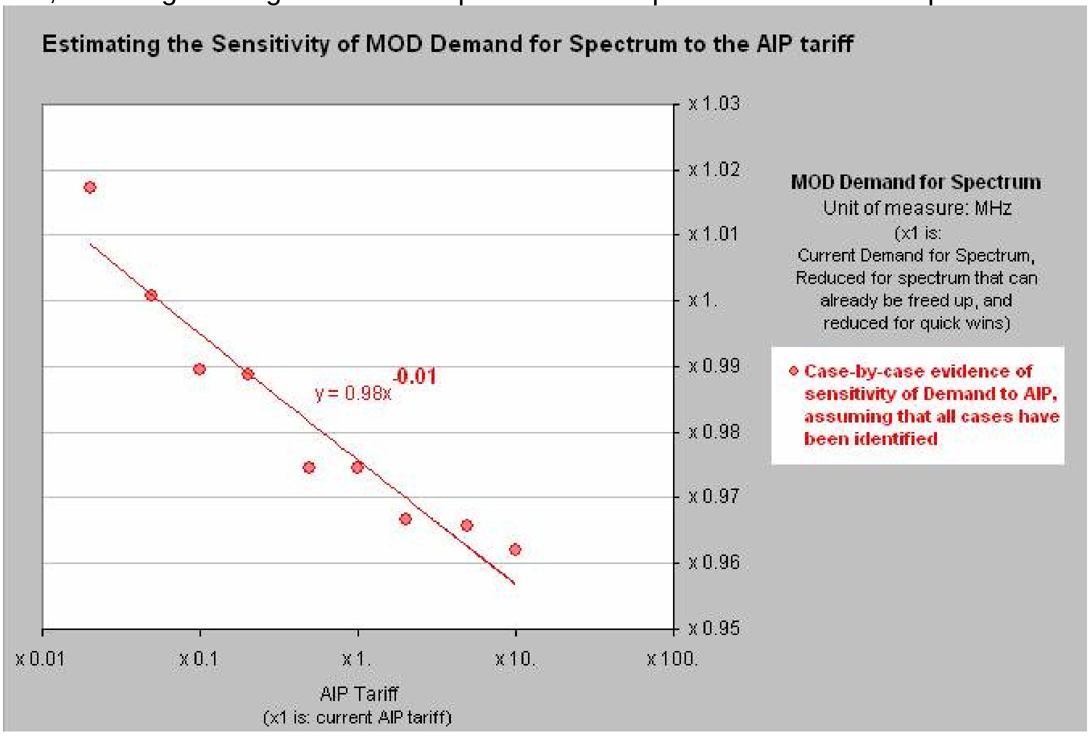

Figure 6-2: Estimating the elasticity of MoD demand for spectrum, to AIP Tariff

This assessment of the elasticity is, however, only valid so long as all of the price-sensitive cases have been identified and assessed in full. It is possible that there are some additional cases of AIP-sensitive systems, not identified in our assessment, where demand will reduce as AIP rises.

Figure 6-3 below shows what the estimate of elasticity might be if additional cases of AIP-sensitive demand for spectrum were to emerge from a full audit of every MoD system:

- The red line is the same as in the previous chart (elasticity -0.01)
- The green line shows what the relationship would be if there were two latent similar cases of sensitivity to AIP for every one case identified in our assessment above. (elasticity -0.03)
- The blue line shows what the relationship might be if every MoD system had the same degree of sensitivity to AIP as the seven or eight most sensitive cases identified in Section 6.4 above. (elasticity estimated at -0.14)

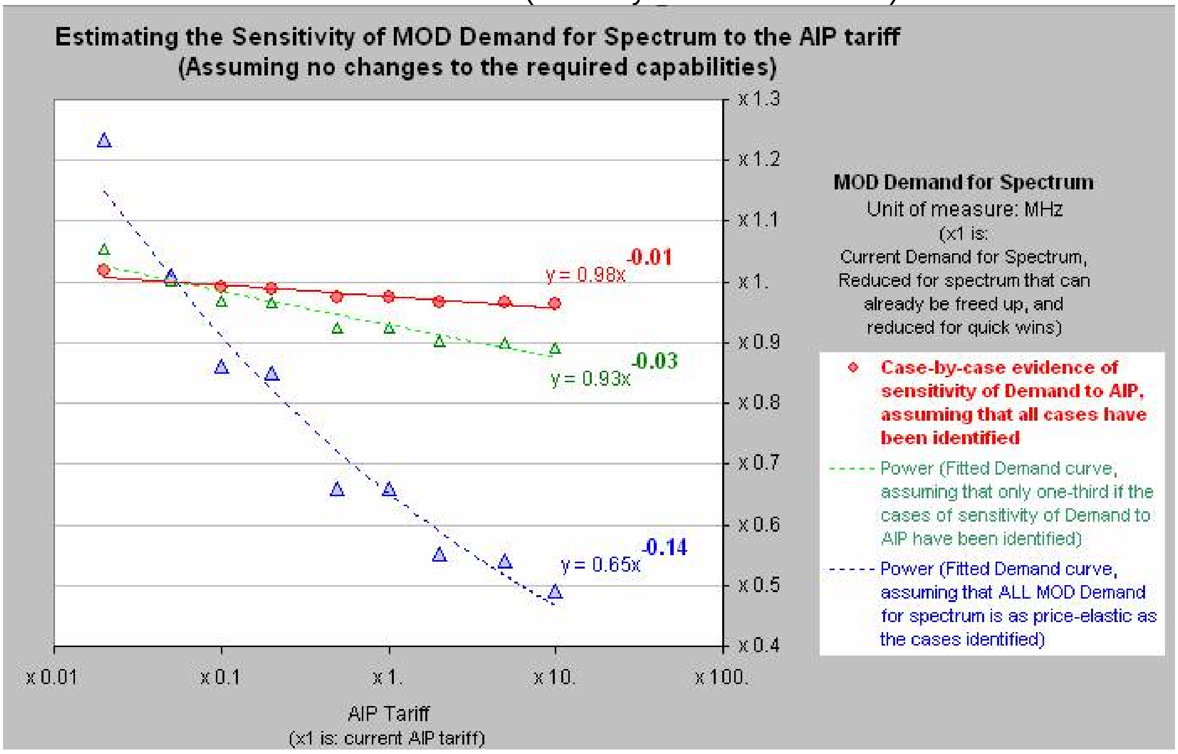

Figure 6-3: Range of estimates of the elasticity of MoD demand for spectrum, to AIP Tariff

We advise caution in drawing empirical inferences from this analysis of elasticity, but the data suggests that the price sensitivity of MOD demand for spectrum, assuming no change in required capabilities, is in the range 0 to -0.1, and likely to be closer to zero than the -0.1.

6.6 CONCLUSIONS FROM THE ECONOMIC MODELLING

Figure 6-4 summarises the findings from assessing each of these systems.

Econometric assessment:							
Individual system: ……………….	***Case 1.1***	***Case 2.1***	***Case 3.1***	***Case 3.2***	***Case 3.3***	***Case 3.4***	***Case 4.1***
	Voice and Data	***Nav. Aids***		***Defence & Weapons Radars***			***Other***
	PMR	***C130 SKE***	***Banshee***	***Watchman***	***T101***	***T93/102***	***Reaper***
Current AIP:							
Current AIP tariff	£ 400 k pa	£ 120 k pa	£ 120 k pa	£ 240 k pa	£ 240 k pa	£ 240 k pa	£ 240 k pa
very approximate breakeven AIP for change	£ 40 k pa	most likely: £10k to £50k	probably in the range	within 50% of current AIP	£ 10 k pa	£ 10 k pa	£50k
If MOD stance on Spectrum changes from "HOLD": what	REDUCE	REDUCE / MIGRATE	ELIMINATE	REDUCE	REDUCE	REDUCE	MIGRATE, else SHARE
Sensitivity ...:							
to AIP	LOW	LOW. (In the 3rd choice	MODERATE	HIGH	VERY LOW	VERY LOW	LOW
to Feasibility of change	HIGH	HIGH	NIL	LOW to MODERATE	HIGH	MODERATE	MODERATE
to Risk	HIGH	LOW to MODERATE	MODERATE	LOW to MODERATE	MODERATE	n/a	HIGH
to Cost of change	MODERATE	LOW to MODERATE	n/a	HIGH	LOW to MODERATE	MODERATE	LOW
scope to reconsider the UK capability requirement?	NIL	NIL	LOW to MODERATE	NIL	NIL	NIL	NIL
Other aspects:							
Estimated Lag (years) to implement the reduction in demand	2 to 5 years	2 to 5 years	2 to 5 years	5 years	2 to 5 years	2 to 5 years	2 to 5 years
Feasibility of regional sharing ?	LOW if the other user wants 100%	LOW to MODERATE	HIGH if not already implemented	Already sharing the band with CAA	LOW	LOW	HIGH

Figure 6-4: Economic assessment - findings for each system

We can draw six conclusions from these assessments of MOD systems with relatively high flexibility and sensitivity to AIP.

1. For many systems, demand is insensitive to AIP, because there is no practical alternative to the current solution and its demand for spectrum, ie. the "curve" is a vertical line[27] i.e. it is price inelastic.

   For some systems there is scope for MOD to trade off between spectrum demand, the level of capability that is planned for, and the attitude to risk, and for these systems the demand for spectrum will alter as AIP takes effect.

   Although it is very approximate, our estimate of the sensitivity to AIP is that the elasticity to the AIP tariff, assuming no flex in the capabilities required of the systems, is between 0 and -0.1, likely closer to the former figure rather than the latter.

2. In the most promising bands covered by the econometric analysis, current levels of AIP are likely to have the following impacts[28] on existing systems:

   - Reduce or migrate systems that account for 10%-20% of spectrum holdings
   - For this 10%-20%, reduce spectrum demand and AIP charges by 50%.

[27] Barring a change to capability requirement, which is outside the scope of this study.

[28] Excluding quick wins and changes already in the pipeline, notably the introduction of T101 radar and the withdrawal of T93 radar.

For these bands as a whole, this will reduce spectrum demand by 5%-10%, and AIP charges by 10% to 20%.

These assessments cover the responses within the life of the existing equipment and typically they could be expected to materialise over a time frame of two to five years.

3. In the remaining bands, the sensitivity to AIP tariff is likely to be less. The remaining AIP charges are more modest (£43m, set against £179m in the bands covered by the econometric analysis), so there is rather less incentive to change existing equipment.

   By the standards of the ability to analyse demand in the commercial sector, there is little empirical evidence regarding sensitivity to price, so these inferences should be treated with caution. The discussions we have had with stakeholders suggest that, for most systems, short term elasticity to price is close to zero, and AIP would have to change by several orders of magnitude (up or down), before it would have a rapid impact on their demand for spectrum.

4. In the longer term, as AIP is factored into MOD thinking and the assessment of options for future systems, some response to AIP can be expected to filter through, and the elasticity may increase. Price signals may influence decisions in procurement and in operations. There is also likely to be greater consideration of looking across different systems, to coordinate the delivery of capability, to achieve more efficient use of spectrum – either reducing AIP charges, or delivering additional capability for the same AIP. Ultimately there may even be some forced reconsideration of whether all of the required capabilities are still essential, in much the same way as normal budgetary pressures force such such issues ot be reconsidered periodically.

5. For those systems that do have some flexibility, other issues have a larger impact than AIP, such as:

   - the feasibility of change in reality
   - how much change would disrupt ‘business as usual’
   - how much it would cost to change

   Whilst it is possible to assess each system individually, and in some cases to find ways to reduce demand for spectrum, the effect on total MOD demand is often more modest, because another user or system shares the band. In some cases it is possible to consider small groups of related systems where there is scope to share spectrum.

6. There are prospects for regional or temporal sharing or subletting; for example, if a 3rd party can accept 99.9% availability of the spectrum, or the possibility of eviction in 10 or 15 years' time, then the spectrum can be shared or sublet.

6.7 COST OF SHARED SPECTRUM – PRICING MODELS

With spectrum sharing emerging as a more fertile ground than straightforward spectrum release, it would seem appropriate to consider the basis on which the costs of spectrum might be shared.

In bands where MOD is releasing some of the rights to spectrum, e.g. by geography or by temporal sharing, there are arguments in favour of sharing of spectrum costs pro rata to the likely value of its use. For most bands, that suggests three drivers of charging:

- population coverage
- land area
- degree of control over the arrangements.

We have also briefly considered potential AIP saving through temporal sharing. However, recognising that the major emitters and training requirements are 24/7 requirements, we believe that significant changes to exercise regimes would be necessary.

For a typical commercial user, the first and third of these would be of great importance. Population coverage means customers and users. In these cases, land area would be of limited relevance.

In cases where MOD is retaining the spectrum in some geographies and Ofcom is releasing the remainder, a range of possibilities arise. These include:

- MOD pays AIP proportional to the population coverage (or land area, but this would seem to be at odds with commercial thinking) of the area retained in MOD hands
- The same approach but with modifications for areas that MOD has earmarked for release but for which no alternative customer has yet been found, and for any pre-emptive rights that MOD retains (e.g. the right to reclaim the spectrum in 15 or 20 years' time)
- Ofcom releases the spectrum, at a fair market price, and the proceeds are shared on some basis with MOD.

In terms of setting a framework that drives the right behaviours, ie. decisions that help the overall use of spectrum in the UK, the last of these approaches seems to have some advantages, and the more that the revenue sharing becomes in effect a pass through of revenue to MOD, the more the true opportunity cost to MOD starts to resemble the true market value of the spectrum rights.

6.7.1 For spatial sharing to work, boundary effects need to be considered

The other consideration would be the approach taken to defining the boundary of usage; a technology and service neutral starting point for shared spectrum users might run along the lines of "transmissions must only occur within the assigned area and must be within xdB of the noise floor at all locations at the boundary of / outside the assigned area". So for example consider the following base case where two users can share the same frequencies[29]:

- A system with an interference range of 80km used at a MOD location in southern England, 100km west from the M25, and at other locations in the north of England, the south west, and in Scotland, Northern Ireland, and Wales, with spectrum licensed for everywhere outside the M25.
- A commercial system with an interference range of 500km, with spectrum licensed just for inside the M25.

Now consider some alternatives:

- The MOD wishes to increase the transmit power of the system, increasing the interference range to 110km. This would breach MOD's spectrum usage rights, because it would cause interference inside the M25.
- There is a desire to relocate or replicate the MOD system at another site, 70km from the M25. Again this is not acceptable, because it would cause interference inside the M25. MOD would have to find an alternative solution, e.g. a different site, or operate the at reduced RF power.
- The commercial user wishes to place numerous additional omni-directional transmitters just inside the M25, still inside their licensed area. Again this is not acceptable, because it will cause interference outside their licensed area. They would have to find an alternative solution, e.g. using transmitters that are directional, or operate at a lower RF power, or negotiate some additional rights with the parties holding licences for the neighbouring areas. In this example, MOD would perhaps have few objections to the rollout, since it is too far from the MOD site to cause interference, but the commercial user would need to accept that some of their sites close to the M25 on the western side of London would suffer from interference from the MOD site.
- The commercial user wishes to extend their coverage in the SE of England, placing numerous additional transmitters outside the M25. Again this is not acceptable, because it will cause interference outside their licensed area. However, there may be room for negotiation:
  - MOD may allow the boundary to be changed, at a price to be determined (which may be based on the value to the commercial network and/or the cost to MOD e.g. if it involves relocating the site currently 100km west of London to somewhere further away)

[29] Making some simplifying assumptions about the RF interfaces, eg that the "interference range" define the acceptable noise threshold, that transmit power and receive sensitivity of the two systems are in a similar balance, and that both parties adhere to the licence specification rather than allowing some give and take, and ignoring special circumstances such as non-peacetime requirements.

  - MOD may allow the extension of the commercial network into its area, on the understanding that the commercial network may suffer greater interference at sites outside the M25. Again, the basis for compensation would need to be determined.

- MOD determines that it can release the spectrum in the south west of England. Market testing indicates that this geographical coverage does not currently have sufficient critical mass to stimulate interest in the spectrum rights beyond a nominal value. Ofcom and MOD will need to have clear ground rules for this type of situation, to indicate e.g. how the regional rebate or discount for foregoing the spectrum in the SW would be determined, and how the situation would alter if these rights were to become commercially valuable in future.

The key conclusions here are that

- Boundary effects are important: "usage" of spectrum extends to cover the area where interference is caused, not just the area where there is transmission
- Areas parcelled up for spectrum sharing need to be attractive to other spectrum users, and, potentially, to their customers too
- Spectrum has to be wholly paid, so if one user's system occupies just a small area of the country, but this means that no-one wants to use the spectrum anywhere else, than that user has to pay the national AIP.

6.8 REDUCING SPECTRUM COST BY REDUCING CAPABILITY

Although the main emphasis in this work has been to look at demand for spectrum *without reducing capability*, we have also considered what changes in capability would be necessary to reduce AIP levels by, for example, 10%.

There are approximately 200 entries in our model making up the total Defence demand for spectrum, consisting of different systems either using spectrum exclusively or sharing with other systems. An edited extract of this list showing the systems that require access to spectrum with an AIP of greater than £10M is given in Figure 6-5 below. Note: the AIP values quoted below assume that no other system shares that same allocation; in practice, removing one system may not free up the allocation completely.

Band identifier	Max Spectrum that this Equipment Record might have to fund, MHz	Service	Capability Family [Comms Type]	Raw Channel Bandwidth (MHz)	**AIP if this Equipment had to pay for a national licence to cover all of its Ubiquitous and non-Ubiquitous demand (ie not sharing the cost with other MOD systems or with non-MOD users)**
2,700 to 3,100 MHz	122.5 MHz	AIR	B	3.5 MHz	**£ 29 m**
2,700 to 3,100 MHz	63. MHz	AIR	C	3.5 MHz	**£ 15 m**
2,700 to 3,100 MHz	60. MHz	FLEET	C	10. MHz	**£ 14 m**
2,700 to 3,100 MHz	56. MHz	AIR	C	3.5 MHz	**£ 13 m**
3,100 to 3,400 MHz	100. MHz	AIR	D	100. MHz	**£ 12 m**
230 to 380 MHz	56. MHz	LAND	A	2. MHz	**£ 11 m**
2,700 to 3,100 MHz	40. MHz	FLEET	C	10. MHz	**£ 10 m**
230 to 380 MHz	48. MHz	LAND	A	0.5 MHz	**£ 10 m**

Figure 6-5: System AIP costs where greater than £10M

System names are included in Appendix H, but from the table above it can be sent that most of the major single 'users' of AIP are wide bandwidth (radar) systems in the 3GHz range. To eliminate a single system with a significant contribution to AIP cost would have a major effect on UK Defence capability and, as noted above, bands are generally shared so eliminating one system may not obviate the need for a particular allocation.

Additionally, we can see from the table above that there are only eight systems that singly account for more than £10M of AIP. To have a significant effect without affecting these would therefore affect large numbers of systems across many aspects of Defence.

Whilst these avenues should be explored, we expect regional sharing and re-banding to provide better results in the shorter term.

6.9 USING THE COST OF SPECTRUM TO GUIDE DECISIONS ACROSS MOD

6.9.1 Factors affecting spectrum cost

From the analysis above, it can be seen that reductions in AIP levels are possible. In order to achieve these it is necessary to consider:

- Spectrum that is currently not in use nationally
- Spectrum that is currently not in use regionally
- Systems that have spectrum allocated to them that either don't use that spectrum, or could use less of it (e.g. multi-channel systems)
- Systems that could be re-engineered to use a lower cost band, or to share spectrum more effectively.

Looking into the future it will be necessary to take the cost of spectrum into account when planning new equipment procurement. The additional cost of incorporating 'training modes' which use less spectrum could well be economically viable.

6.9.2 Modelling the cost of spectrum

The main economic model that we have developed for this study enables MOD to examine the cost of spectrum usage band-by-band, down to the level of specific equipments. Alternative scenarios can be run to look at the impact of system design on spectrum cost.

7.1 ALLOCATING SPECTRUM CHARGES TO USERS

7.1.1 Spectrum value depends on population, assuming that some basic criteria are met

As discussed above, the commercial value of spectrum is determined by the frequency band (and hence its range and applicable services) and predominantly the number of subscribers that can be served in that band[30].

Firstly, it seems reasonable that spectrum costs should flow down to the equipment owner in the same way as any other ongoing resource cost. It would be considered by the IPT before Main Gate as part of the Through Life Cost, and would be balanced with other options to achieve the best result.

However, AIP is a mechanism for encouraging efficient use within public bodies, but to pass incentives down to IPTs to select the optimum frequency of operation is more complex. Calculating the 'cost' of the spectrum is complex and there are a number of options and issues.

7.1.2 How should the operating frequency of equipment be chosen

In principle the IPTs should choose the operating frequency of new equipment as part of their development cycle, with a view to maximising capability at minimum cost. To achieve this IPTs would need to be given a clear view of the through life spectrum cost.

The Value of Spectrum – AIP or Opportunity Cost

Cost based on AIP is one measure by which IPTs could account for spectrum, on the basis that this is the charge that is levied on MOD. However, since MOD may have the potential to sell spectrum in future, this does not reflect the true *opportunity cost* of the resource. It can be argued that market value should be the metric against which decisions are made.

Cost based on market value is unfortunately also problematic, since it can fluctuate widely with commercial fashions, and using this as a metric could lead to some expensive mistakes in the long term. Also, since MOD would only be able to retain some part of the market value (the remainder would flow to treasury) a more complex formula would need to be applied.

[30] The other drivers would vary from application to application and would include preferences for (in approximate order of priority): large contiguous areas (to reduce the inefficiency of having fringe areas used as guard zones, and to provide clearly defined propositions and markets for end consumers), densely populated areas, transport corridors, and large areas of land, coast, or sea.

From the viewpoint of MOD or of an IPT, spectrum is a resource for which term cost commitments are being made over an extremely long time frame, typically 20 to 40 years, and it is desirable for the forward AIP tariff to be known in advance. The system owner can then commit to a set of spectrum rights at a more-or-less known through life cost. If the value of that spectrum changes in future – for example if the band becomes of great interest to the commercial sector due to it being designated for a future generation of mobile networks – the system owner would then be able to recoup the value of that spectrum at the new AIP. Conversely, if the band was of some commercial value but becomes less valuable, system owners would be able to add to, or reduce, their spectrum holdings at the new (lower) AIP. This approach ensures that system owners are presented with the correct financial incentives at the decision points over the life of the equipment: specification and procurement, initial deployment, operations, mid-life review, and replacement or disposal.

Ensuring that IPT and MOD interests are aligned

There is an additional difficulty if spectrum usage decisions are passed down to the IPTs in that they will rightly make a decision that yields the best result for their project. However, this may not be the optimum result from a wider MOD viewpoint.

If, for example, an IPT selected a relatively low value unused band to operated in instead of a shared high value band, it might achieve lower spectrum costs (100% of the AIP charge in the low value band could be less than a share of the AIP charge in a high value band). However, MOD would be paying more for spectrum overall.

Similarly, MOD could make significant savings through a comprehensive band strategy – concentrating traffic in fewer bands and maximising geographic reuse.

In order to achieve the optimum result for MOD we believe that some level of central coordination and direction is needed; at present this would rest with CBM(J6).

7.1.3 Allocating costs between users

Having decided on what basis spectrum should be charged, the next question is how to distribute that cost between multiple users.

Projects are charged the full AIP cost for the spectrum they are using

This is perhaps the simplest approach, but falls down when frequencies are shared across the country. Without some split of cost, MOD will be over-recovering AIP from the various systems.

Projects are charged the AIP cost for the spectrum they use over the population that they preclude from using the band for other purposes

This goes a long way to producing a 'fair' model, since over-recovery would not occur under this model. However, there are still a number of issues with this:

- It may be that MOD's partial use of the band over some of the country makes it unattractive to commercial users. In this case there is an argument that the MOD user should pay the full national AIP for that band (becomes closer to the opportunity cost).
- If a number of MOD users share the band geographically, they should together pay the full AIP charge, to avoid under-recovery of AIP. This would imply some form of weighting according to population covered by each of the systems in use.

- If another user enters the band, the costs should be recalculated to reduce the AIP charge to the incumbents.
- If a user leaves the band the situation is more complex. It might be considered to be unreasonable to penalise a user with costs that they could not reasonably foresee, in which case MOD would arguably have to pick up the shortfall centrally. An alternative argument could be that the situation is the same as with any other resource and prices may fluctuate, although this could leave small system owners with a disproportionate spectrum charge.

7.1.4 An overall charging model

It is beyond the scope of this report to recommend an overall charging model for spectrum. However, our findings so far suggest that the following elements should be part of any model:

- A combination of AIP and market value (opportunity cost) should be taken as the basis for charging users for spectrum
- A forward view of AIP needs to be established and used as the basis for decisions related to spectrum demand
- Charges to users should be based on the population in the area that they preclude from usage by commercial systems
- Where new systems enter a band, AIP charges may be shared
- Where systems exit the band unexpectedly, costs may have to be picked up centrally. Changes in sharing of charges because of equipment reaching its planned out of service date should be foreseen and taken into account in Through Life Costing of new systems.
- There is a need for a central frequency coordination / direction body to ensure that MOD gets best overall value from its spectrum.

8. CONCLUSIONS

Our overall conclusion from this study is that there are a number of opportunities for MOD to release spectrum either nationally or regionally and reduce its exposure to AIP charges. However, this needs to be done with great care because of increasing demand for spectrum over the next 10 years, particularly driven by the need for increased voice and data communications with land forces, and the need for higher performance radars on attack aircraft.

8.1 SPECTRUM DEMAND – 2010

We have examined demand for spectrum in 2010, based on our findings from many discussions with users and other stakeholders. From these discussions we have built a model of demand which we have analysed from various perspectives.

Spectrum demand can be broadly categorised into:

- Voice and Data Links
- Navigational Aids
- Defence and Weapons Radars
- Other (includes Satcoms, Microwave links, other radars etc.)

The largest user of spectrum is the 'Defence and Weapons Radars' category, occupying nearly 50% of MOD spectrum; this is followed by 'Voice and Data Links' and 'Other' at approximately 20% each, and 'Navigational Aids' at less than 10%. These are the primary applications that need to be considered when reviewing options for release or acquisition of spectrum.

In addition to the primary MOD applications in the various bands, we found a large number of 'opportunistic' applications, where systems that are typically low bandwidth and / or geographically restricted have been placed in a band used by a 'primary' application. Whilst these opportunistic uses could almost certainly be relocated to an alternative band, their presence does need to be recognised and handled appropriately.

It should also be noted that significant changes are happening around 3GHz because of system changes which need to be taken into account when considering demand in those bands. These changes also mean that this demand study shows different results to the band audit.

8.2 SPECTRUM DEMAND CHANGES TO 2015

The major changes in demand out to 2015 are as follows:

- Potential significant increased demand in the bands from 230MHz to 450MHz arising as a result of increased need for communications with and between Land forces.
- Changing demand around the 3GHz region as new radar systems take over from existing ones
- Very significant increase in demand in radar bands above 9GHz with the introduction of Joint Strike Fighter and other platforms

8.3 FREQUENCY RELEASE AND REQUIREMENTS

Supply Exceeding Demand

There are some bands which appear to have surplus capacity in the 2008 – 2015 timeframe:

- 380 – 450MHz *appears* to have some combined spare capacity on a national basis. This could potentially be increased by moving out some PMR systems to other providers. The cautionary note here is that requirements for FIST and other NEC programmes will need frequencies in this region to satisfy their propagation range requirements; future needs are emerging and will not be understood fully for the next 2-3 years.
- 3.1 – 3.6GHz are already being considered by MOD
- 4.4 – 5.0GHz appears to have potential for release of up to 25% of the frequency range (170MHz), with an AIP value of £2.75M.
- 5.3 – 5.85GHz appears to have even more scope, with potential for releasing up to 80% of the range (280MHz) with an AIP value of £4.8M.

There is a risk with this; looking out to 2027 we see a need for significant additional bandwidth which could be satisfied by these bands, although it is still doubtful if all the spectrum will be required.

Demand Exceeding Supply

- 230 – 380MHz appears to be busy in 2010 (despite having spare spectrum today) with the prospect of additional demand between 2010 and 2015
- 2.7 – 3.1GHz will become more heavily used by 2010
- 9.0 – 9.5GHz and 14.62 – 15.23GHz bands appear to be particularly heavily oversubscribed with weapons radars – in practice these appear to co-exist
- 13.4 – 14.0GHz will become oversubscribed by 2015

8.4 GEOGRAPHICAL SHARING

Geographical sharing appears to offer considerable potential for spectrum release, particularly around the high value bands.

Whilst it will not be possible to realise all the potential value, our modelling suggests that the ‘unused’ AIP amounts to approximately £50M nationally. Realising this would of course require a completely matched set of commercial demand. A more realistic view might be that £10 – 20M could be realised from geographic sharing.

8.5 DEMAND TO 2027

Looking out beyond 2015 to 2027 is inevitably less precise. We have considered future capability by reviewing the Defence Plan and various other MOD reference sources concerned with future capability. Additionally we have reviewed current MOD research programmes to understand where these may be recommending the use of additional spectrum. Finally we have considered advances in technology that are likely to impact spectrum demand.

Communications systems will demand additional VHF / UHF bandwidth

We find that many of the LAND R&D programmes are concerned with delivery of situational awareness and are seeking improved data communications with troops. Programmes such as FIST, Future Dismounted Close Combat, ESII and NEC for Close Combat are all working towards systems that require additional radio bearer capacity, mainly in the VHF / UHF bands. They also call for additional Satcom usage.

Technological improvements are unlikely to mitigate this, although some of the dynamic channel allocation techniques being researched in DARPA are of interest.

Radar systems will require additional spectrum at X-band and above

We find that demand for very wideband, multi-mode, radar systems in increasing, noting particularly weapons systems on new attack aircraft.

Air Traffic Control radars will improve in spectral efficiency

Technological improvements will help in the ATC area with the trend towards CW radars, leading to potential release of spectrum around the 3Hz area..

8.6 THE ECONOMICS OF SPECTRUM DEMAND

Through investigation of various approaches to economic analysis, we concluded that a ‘bottom up’ approach to understanding current and future demand was the most appropriate technique, relying on stakeholder discussions to understand current demand and to predict how that would change in the future. We rejected multi-variate and time-series approaches to predicting demand as requiring data that is not available, and relying on a number of assumptions that are not valid in the Defence domain.

The ‘Demand Building Block’ approach that we have used is resilient to change and locations or systems in use can be changed at will to investigate ‘what if’ scenarios.

Through this analysis, and subsequent examination of specific cases of demand, we concluded that the overall Elasticity of the relationship between AIP Tariff and Defence Demand for spectrum is likely to be significantly less than -0.1 i.e. changes in AIP Tariff at around the current level are unlikely to change demand for spectrum significantly.

Going forward with new equipment procurement, we find that AIP tariff can, and should, impact the selection of operating frequencies and operating modes through, for example, provision of special operating modes for use in the UK where necessary to avoid high AIP charges.

We also briefly examined the extent to which capability might have to be reduced in order to reduce AIP charges, and came to the conclusion that to reduce AIP by, for example, 10%, would have a disproportionately high impact on capability. Whilst these results have been arrived at only through high-level considerations, they are in line with the earlier discussion of Elasticity suggesting that, at current AIP levels, capability provision is unlikely to be sensitive to small changes in AIP.

8.7 OTHER ISSUES

Allocating spectrum cost to users is inevitably contentious and we considered alternative ways in which this might be done. Our conclusion is that spectrum should be managed in the same way as any other resource required by a capability or system, with charges flowing to the user. However, this is a complex issue where spectrum is shared and we have proposed some potential formulations of charging regimes.

8.8 OVERALL CONCLUSIONS

In summary, we conclude that MOD generally intensively uses the spectrum it has access to in order to deliver capability. There are some bands where spectrum could be released or where usage could be more efficient, but there are equally bands where MOD demand appears to exceed supply and operational compromises are being made, or systems are co-existing where simple theory would suggest a problem. We believe that geographical sharing holds considerable potential, as does re-banding of some systems to avoid high AIP bands.

9. RECOMMENDATIONS

9.1 RECOMMENDATIONS FOR BAND-SPECIFIC ACTIONS

In this section we note the major actions that we believe should be taken in specific bands. These should be seen in the overall context of band-sharing, frequency release, and geographic re-use.

9.1.1 230MHz – 380MHz
380MHz – 400MHz
401.5MHz – 406.1MHz
410MHz – 430MHz
430MHz – 450MHz

We recommend that MOD should initiate a study into PMR usage in these bands. This study would form a pathfinder for other similar band-specific studies Additionally, geographic sharing should be considered in this band.

Overall we caution against the release of spectrum below 1GHz because of upcoming NEC requirements. Further, we believe that MOD may need to re-locate some systems that currently operate in those bands in order to make way for FIST and other NEC-related equipment.

9.1.2 2310MHz – 2390MHz

We recommend a detailed localised study of likely peak loading and propagation at Aberporth and Hebrides to determine accurate demand and the ability to share this band on a geographical basis with these relatively remote sites.

9.1.3 2700MHz – 3100MHz

There is potential for reducing demand by carrying out a more detailed study of the potential co-existence of ASACS radars with other land-based systems within this band.

9.1.4 3100MHz – 3400MHz

There appears to be an opportunity for some national spectrum release in this band, although SAMPSON radars (details unavailable) may affect this.

9.1.5 3400MHz – 3600MHz

Given the potential commercial attractiveness of this band, it is worth considering whether the Hercules SKE markers could be re-banded into another band. This could effectively free up the entire band.

Additionally, the value of this capability should be investigated given its sporadic use and limited numbers of equipment.

9.1.6 5300MHz – 5650MHz

A detailed demand study of COBRA and MAMBA training and testing usage could deliver savings in this band, if their spectrum demand could be shared across time and geography, giving better re-use of frequencies across the two systems.

It can be noted that some of the systems in this band (MOTR, MAMBA) are also present in other adjacent bands. It may be worth studying the potential for consolidating these systems into a single band in order to free up spectrum further.

9.1.7 5650MHz – 5850MHz

It can be noted that some of the systems in this band (MOTR, MAMBA) are also present in other adjacent bands. It may be worth studying the potential for consolidating these systems into a single band in order to free up spectrum further.

9.1.8 8500MHz – 8750MHz

As noted for Band 30 (2700MHz – 3100MHz), we currently assume that surveillance and weapons radars need to be de-conflicted using different channels. If, in practice, this de-confliction can be achieved using pulse profiling (or other techniques) to differentiate radar transmissions in the same channel, this will reduce the number of channels needed and therefore reduce the total spectrum demand in this band.

9.1.9 9000MHz – 9500MHz

As for Band 42 above, this band represents part of a very busy area of spectrum between 8500MHz – 10000MHz. Looking across that wider band and within this band itself, there seems little prospect of a national release of spectrum in this band.

MOD should consider where potential ‘overspill’ from this band should be placed in future.

9.2 RECOMMENDATIONS TO IMPROVE FREQUENCY ALLOCATION PROCESSES WITHIN MOD

9.2.1 Taking spectrum cost into account in procurement

MOD already has comprehensive ‘Through Life Cost’ regimes defines which are used at Initial Gate of the CADMID procurement cycle. These should be updated to include the cost of spectrum, and to encourage consideration of alternative frequency bands.

9.2.2 Cost allocation

It seems logical to us that the cost of spectrum should be allocated in the same way as the cost of any other resource necessary to operate the system (e.g. fuel, manpower, spares etc.). There are complications arising where spectrum is shared but they should not be allowed to stand in the way of appropriate charging models. It does need to be recognised that the users of the equipment will have had no control over the design and frequency plan, so a transition period will be necessary to avoid unwanted side-effects.

9.2.3 Central coordination

Whilst we recognise the benefits of giving information and authority to IPTs, we believe that a central spectrum management role is necessary to achieve the best result for MOD overall. This should deal with issues such as:

- band consolidation (achieving the highest possible spectrum use within a band)
- band selection (avoiding expensive bands, putting plans for clearance in place and avoiding new systems creeping into bands to be cleared)
- negotiations with Ofcom and other users.

This role is currently filled by CBM(J6), and we see no reason from our this study why this should change.

9.2.4 System specifications – getting the best use of spectrum

IPTs should be encouraged to consider ways of reducing demand for spectrum *in the UK* that do not affect operational capability. These might include provision of low power modes, reduced channel sets etc.

9.2.5 Communications

We believe that there will be value in keeping users informed about current and future use of spectrum, to inform understanding of interference issues, efficient spectrum use, and to enable informed debate within MOD about best use of spectrum. This might take the form of a quarterly newsletter issued to users, IPTs, DECs and Dstl.

9.3 DATA MAINTENANCE

MOD should update this overall view of spectrum use approximately every 3 years. A ‘rolling review’ cycle, focussed initially on bands of interest, should be initiated. It would be appropriate to review all key bands in detail every 5-7 years (some of the higher frequency bands may not need to be reviewed as frequently).

There is a need for a forward-looking database of potential spectrum demand and usage.

9.4 OTHER RECOMMENDATIONS

9.4.1 Regional sharing

MOD should commission a study to determine the potential regional opportunities for regional sharing and their return in AIP saving.

MOD should propose and agree (with Ofcom) AIP cost models for regional sharing.

9.4.2 Future requirements

MOD should urgently commission a study into the UHF bands to consider how to meet future demand for LAND communications systems.

9.4.3 Potential spectrum release

MOD should examine key bands of interest identified in this report with a view to releasing spectrum.

APPENDIX A UK DEFENCE SPECTRUM BANDS

Band Edges (MHz)		Net width MHz)	AIP per MHz £k)	New Total AIP (£'K)
70.0	70.5	0.5	£132k	£66
72.8	74.8	2.0	£132k	£259
75.2	76.7	1.5	£132k	£198
78.0	80.0	2.0	£132k	£264
83.5	85.0	1.5	£132k	£198
137.0	138.0	1.0	£325k	£312
141.9	143.0	0.5	£325k	£162
149.0	149.9	0.9	£325k	£292
153.5	154.0	0.5	£325k	£162
230.0	380.0	150.0	£198k	£29,700
380.0	400.0	10.0	£198k	£1,980
401.5	406.1	6.0	£396k	£2,356
406.1	410.0	3.9	£396k	£1,544
410.0	430.0	16.0	£396k	£6,336
430.0	450.0	20.0	£396k	£7,920
870.0	872.0	2.0	£396k	£792
876.0	880.0	3.0	£396k	£1,188
915.0	917.0	2.0	£356k	£713
921.0	925.0	3.0	£356k	£1,069
960.0	1,215.0	127.5	---	---
1,215.0	1,350.0	67.5	---	---
1,375.0	1,400.0	25.0	£297k	£7,417
1,427.0	1,452.0	25.0	£297k	£7,417
2,025.0	2,070.0	45.0	£277k	£12,483
2,200.0	2,245.0	45.0	£277k	£12,483
2,310.0	2,390.0	80.0	£237k	£18,954
2,390.0	2,450.0	5.0	£237k	£1,185
2,700.0	3,100.0	280.0	£238k	£66,618
3,100.0	3,400.0	300.0	£118k	£35,538
3,400.0	3,600.0	120.0	£118k	£14,215
4,400.0	5,000.0	600.0	£18k	£10,560
5,000.0	5,150.0	75.0	£19k	£1,395
5,300.0	5,650.0	350.0	£18k	£6,160
5,650.0	5,850.0	100.0	£18k	£1,760
7,250.0	7,400.0	150.0	£13k	£1,980
7,900.0	7,975.0	75.0	£13k	£990
7,975.0	8,025.0	50.0	£13k	£660
8,025.0	8,400.0	375.0	£13k	£4,950
8,500.0	8,750.0	250.0	£13k	£3,300
8,850.0	9,000.0	150.0	£8k	£1,140
9,000.0	9,500.0	250.0	£9k	£2,150
9,500.0	10,125.0	625.0	£8k	£4,750
10,125.0	10,225.0	50.0	£8k	£380
10,225.0	10,475.0	130.0	£8k	£988
10,475.0	10,500.0	12.5	£8k	£95
13,250.0	13,400.0	150.0	£9k	£1,290
13,400.0	14,000.0	300.0	£8k	£2,280
14,620.0	15,230.0	610.0	£8k	£4,636
15,400.0	15,700.0	150.0	£9k	£1,290
All the above bands		5,798.7 MHz	£ 49 k	£282,575

APPENDIX B TOP 20 FREQUENCY BANDS

Loc x DBB Scenario sheet: **LocxDBB 2008 Run 10**
Equipment Records Scenario sheet: **ER Run 10**
ER: (i) Date and (ii) Demand Scenario: **2010 / Peak**

Priority	Band Name	MoD Demand, met within (Gross) Supply	Apparent Spare Spectrum (Net Supply in excess of MoD demand)	Unavailable, Shared. (ie: Gross supply, minus the higher of: MoD Demand, or Net supply)	MoD Demand, in excess of (Gross) Supply
A. In Top 20	Band 10: 230 to 380 MHz	150. MHz	---	---	15.1 MHz
A. In Top 20	Band 11: 380 to 400 MHz	0.3 MHz	9.7 MHz	10. MHz	---
A. In Top 20	Band 12: 401.5 to 406.1 MHz	1.53 MHz	3.08 MHz	---	---
A. In Top 20	Band 14: 410 to 430 MHz	9. MHz	7. MHz	4. MHz	---
A. In Top 20	Band 15: 430 to 450 MHz	15.88 MHz	4.13 MHz	---	---
A. In Top 20	Band 28: 2,310 to 2,390 MHz	80. MHz	---	---	3.3 MHz
A. In Top 20	Band 30: 2,700 to 3,100 MHz	400. MHz	---	---	17.5 MHz
A. In Top 20	Band 31: 3,100 to 3,400 MHz	175. MHz	125. MHz	---	---
A. In Top 20	Band 32: 3,400 to 3,600 MHz	56. MHz	64. MHz	80. MHz	---
A. In Top 20	Band 33: 4,400 to 5,000 MHz	477. MHz	123. MHz	---	---
A. In Top 20	Band 35: 5,300 to 5,650 MHz	46. MHz	304. MHz	---	---
A. In Top 20	Band 36: 5,650 to 5,850 MHz	48.8 MHz	51.2 MHz	100. MHz	---
A. In Top 20	Band 37: 7,250 to 7,400 MHz	150. MHz	---	---	0.5 MHz
A. In Top 20	Band 40: 8,025 to 8,400 MHz	375. MHz	---	---	10. MHz
A. In Top 20	Band 42: 8,500 to 8,750 MHz	250. MHz	---	---	4. MHz
A. In Top 20	Band 44: 9,000 to 9,500 MHz	500. MHz	---	---	629.3 MHz
A. In Top 20	Band 45: 9,500 to 10,125 MHz	552. MHz	73. MHz	---	---
A. In Top 20	Band 49: 13,250 to 13,400 MHz	91. MHz	59. MHz	---	---
A. In Top 20	Band 50: 13,400 to 14,000 MHz	282. MHz	18. MHz	300. MHz	---
A. In Top 20	Band 51: 14,620 to 15,230 MHz	610. MHz	---	---	371.4 MHz
	Total ...	**5,284 MHz**	**1,338 MHz**	**901 MHz**	**2,190 MHz**

Priority	Band Name	AIP per MHz £k	AIP per MHz £k - Within Net supply	AIP per MHz - apparently spare spectrum	AIP per MHz £k - Above Gross supply	AIP charges for Demand - Within Gross supply. NB applied to: Demand, capped at Net supply.	Further AIP charges, only incurred if Apparently Spare Spectrum is retained	Unavailable, Shared. (ie: Gross supply, minus the higher of: MoD Demand, or Net supply, x AIP)	Further AIP charges for Demand in excess of Gross supply
A. In Top 20	Band 10: 230 to 380 MHz	£ 198k	£ 198k	£ 198k	£ 198k	£ 29.7m	£ 0 m	---	£ 3.0m
A. In Top 20	Band 11: 380 to 400 MHz	£ 198k	£ 198k	£ 198k	£ 198k	£ 0.1m	£ 1.9m	£ 2.0m	£ 0 m
A. In Top 20	Band 12: 401.5 to 406.1 MHz	£ 512k	£ 512k	£ 512k	£ 512k	£ 0.8m	£ 1.6m	---	£ 0 m
A. In Top 20	Band 14: 410 to 430 MHz	£ 396k	£ 396k	£ 396k	£ 396k	£ 3.6m	£ 2.8m	£ 1.6m	£ 0 m
A. In Top 20	Band 15: 430 to 450 MHz	£ 396k	£ 396k	£ 396k	£ 396k	£ 6.3m	£ 1.6m	---	£ 0 m
A. In Top 20	Band 28: 2,310 to 2,390 MHz	£ 237k	£ 237k	£ 237k	£ 237k	£ 19.0m	£ 0 m	---	£ 0.8m
A. In Top 20	Band 30: 2,700 to 3,100 MHz	£ 238k	£ 238k	£ 238k	£ 238k	£ 66.6m	£ 0 m	---	£ 4.2m
A. In Top 20	Band 31: 3,100 to 3,400 MHz	£ 118k	£ 118k	£ 118k	£ 118k	£ 20.7m	£ 14.8m	---	£ 0 m
A. In Top 20	Band 32: 3,400 to 3,600 MHz	£ 118k	£ 118k	£ 118k	£ 118k	£ 6.6m	£ 7.6m	£ 9.5m	£ 0 m
A. In Top 20	Band 33: 4,400 to 5,000 MHz	£ 18k	£ 18k	£ 18k	£ 18k	£ 8.4m	£ 2.2m	---	£ 0 m
A. In Top 20	Band 35: 5,300 to 5,650 MHz	£ 18k	£ 18k	£ 18k	£ 18k	£ 0.8m	£ 5.4m	---	£ 0 m
A. In Top 20	Band 36: 5,650 to 5,850 MHz	£ 18k	£ 18k	£ 18k	£ 18k	£ 0.9m	£ 0.9m	£ 1.8m	£ 0 m
A. In Top 20	Band 37: 7,250 to 7,400 MHz	£ 13k	£ 13k	£ 13k	£ 13k	£ 2.0m	£ 0 m	---	£ 0.0m
A. In Top 20	Band 40: 8,025 to 8,400 MHz	£ 13k	£ 13k	£ 13k	£ 13k	£ 5.0m	£ 0 m	---	£ 0.1m
A. In Top 20	Band 42: 8,500 to 8,750 MHz	£ 13k	£ 13k	£ 13k	£ 13k	£ 3.3m	£ 0 m	---	£ 0.1m
A. In Top 20	Band 44: 9,000 to 9,500 MHz	£ 9k	£ 9k	£ 9k	£ 9k	£ 2.2m	£ 0 m	---	£ 5.4m
A. In Top 20	Band 45: 9,500 to 10,125 MHz	£ 8k	£ 8k	£ 8k	£ 8k	£ 4.2m	£ 0.6m	---	£ 0 m
A. In Top 20	Band 49: 13,250 to 13,400 MHz	£ 9k	£ 9k	£ 9k	£ 9k	£ 0.8m	£ 0.5m	---	£ 0 m
A. In Top 20	Band 50: 13,400 to 14,000 MHz	£ 8k	£ 8k	£ 8k	£ 8k	£ 2.1m	£ 0.1m	£ 2.3m	£ 0 m
A. In Top 20	Band 51: 14,620 to 15,230 MHz	£ 8k	£ 8k	£ 8k	£ 8k	£ 4.6m	£ 0 m	---	£ 2.8m
	Total ...		**£ 45k**	**£ 36k**	**£ 63k**	**£ 235.5m**	**£ 48.5m**	**£ 20.4m**	**£ 138.2m**

Summary by type of Band	MoD Demand met	Apparent spare spectrum	Unavailable Spectrum	Demand in excess of supply
A. In Top 20	**4,270 MHz**	**841 MHz**	**494 MHz**	**1,051 MHz**
B. Near Top 20	**291. MHz**	**152.9 MHz**	**150. MHz**	**518. MHz**
C. Other Bands	722 MHz	344 MHz	257 MHz	562 MHz

Summary by type of Band	MoD Demand met	Apparent spare spectrum	Unavailable, Shared. [if this makes sense for AIP?]	Demand in excess of supply
A. In Top 20	**£ 188m**	**£ 40m**	**£ 17m**	**£ 16m**
B. Near Top 20	**£ 41m**	**£ 2m**	**£ 1m**	**£ 79m**
C. Other Bands	£ 7m	£ 6m	£ 2m	£ 43m

APPENDIX C DEMAND BUILDING BLOCKS (IN DETAIL)

C.1 INTRODUCTION

In recognition that getting accurate estimates of spectrum demand from stakeholders would be difficult without offering a scenario-based context, a series of Demand Building Blocks (so called so as not to confuse with the MOD's Studies Advisory Group (SAG) scenarios) were developed to demonstrate localised spectrum demand.

Precedence exists within commercial demand studies that extrapolation from such Demand Building Blocks can form a realistic estimate of consolidated demand. Additionally the Building Blocks were used to highlight exceptions, unique capabilities, locations, or equipment that is not covered by initial data capture.

The Building Blocks were developed around current known defence and military units and locations. The Building Blocks have been kept as generic as possible to allow consolidation. We recognise that the Building Blocks need to be additive so that sites with multiple functions (represented by multiple Building Blocks of the same or differing nature) can be estimated effectively.

C.2 LOCATIONS

We have taken into account what we consider to be the significant locations for spectrum demand. Most land-based locations are intuitive, but we have adapted the technique as follows:

- We have treated fixed wing aircraft as ubiquitous throughout UK airspace, rather than tying them to the geographical location of their parent airfield. The location "UK Airspace" includes a peak number of aircraft that we would expect to see airborne, for example during a major NATO RED FLAG style exercise, rather than being based on squadron or aircraft numbers in the inventory.
- We have treated naval ships as ubiquitous in UK waters. Rather than model different ships with all their individual radars etc, we have modelled generic task groups. We have assumed:
  - 3 surface combatant task groups with a mix of destroyers, frigates and RFAs and their associated helicopters.
  - A carrier task group with its associated helicopters. (The fixed wing aircraft have been captured in the UK airspace location). Its escorts are covered by one of the surface combatant task groups outlined above.
  - An amphibious task group, with embarked Royal Marine units with as mix of ship types. Again, we have covered its escorts separately.

C.3 CURRENT DEMAND BUILDING BLOCKS

The following is an explanation of our DBBs.

- **DS1 - Military Protected Site**. Almost all significant land-based sites within UK have a radio spectrum demand for base security, and local infrastructure communications. Although in the majority of cases there will be other spectrum demands associated with operations or training, there are some headquarters and other locations where such local security and infrastructure requirements form the sole basis for demand. An example would be the HQ Land Forces Command in Wilton.

- **DS2 - A Major Unit in Barracks**. A discrete, typically Army unit in one location. Each unit consists of between 300 and 800 men dependent on role. It will hold some or all of its vehicles and equipment required to complete its training for role, and is largely autonomous. A number of units can be Brigaded, or garrisoned to reduce estate and security overheads. An example of a discrete autonomous unit would be an Infantry Battalion based in Fort George (Inverness). The radio spectrum usage would be limited to a generic set of vehicle and man-portable communications devices, typically Bowman required for basic training for routine operations. Garrisons will contain a multiple set of units, for example Tidworth and Bulford Garrison has 9 Major Units of various roles with two major camps on the edge of Salisbury Plain.
- **DA1 - Air Field**. A discrete operational air base with an active airfield. An example would be RAF Lossiemouth, the largest and busiest fast-jet base in the RAF. This is home to 3 Operational Squadrons of Tornado and the Operational Conversion Unit, and a Sea King Search and Rescue unit. The spectrum demands for an Air Base include Air Navigation aids (including air traffic radar), Air Ground Air communications, tactical data links, and management radios. Some Air bases are the responsibility of the Royal Navy (Yeovilton) and the Joint Helicopter Command (RAF Odiham). Some air bases are for training purposes only and may have special provision (e.g. the Defence Helicopter Flying School at RAF Shawbury).
- **DA2 – Air Squadron**. This DBB typically covers air to air and air to ground communications, including some (effectively) point-to-point data links. It does not cover on-board radars.
- **DA3 - Radar Station (ASACS)**. A discrete AIR capability to provide Air Surveillance for the defence of the homeland, and as part of NATO early warning of Air intrusion. Radar Stations can exist in isolation, for example the remote radar site at Staxton Wold (the world's oldest operational radar site), or are part of active RAF operating bases, for example RAF Scampton. Spectrum demand will include specific radar related spectrum. Because of their significant radiation, and the fact that the different radars operate in different frequencies etc we have subdivided this category to provide a more accurate picture of demand. These sub-categories cover (i) T92 sites, (ii) T93 / T102 sites, (iii) T101 sites and (iv) Fylingdales.
- **DA4 – EW Simulation**. This covers the radiation (both Red and Blue counter-measures) associated with EW simulation. We have subdivided this category, breaking out the major emissions associated with RAF Spadeadam, and that which can be carried out elsewhere.
- **DA5 – UAVs**. This covers the command links and data and video links associated with UAVs.
- **DA6 – ISTAR Air**. This covers the data and video links associated with airborne ISTAR assets. We have broken out ASTOR separately so as not to over-estimate radar demand.
- **DA7 – USAF**. This DBB allows us to cover any unique requirements of USAF bases.
- **DA8 – Air to Air**. This DBB (which is additive to DA2) covers air-to-air radars and missiles with active seeker heads.

- **DA9 – Aerial Targets**. This covers the particular emissions associated with air-to-air targets. This is particularly concentrated in the Hebrides and Aberporth.
- **DA10 – AT Sqns**. This DBB captures weather radars on Hercules C-130, Tristar and C-17, and the C-130 Station Keeping Radar.
- **DM1 – Ship in Harbour**. This DBB covers communications systems, limited navigation radar use, and PMRs for security and other purposes.
- **DM2** - **Naval Operating Base**. A discrete port used as a naval operating base. An example would be Plymouth. A number of surface fleet vessels would be alongside during periods of training, and UK operations. Such operating bases would have a discrete demand for spectrum to manage their infrastructure, maritime navigational aids, and any ship-borne communications tested, in trial or for training per ship alongside
- **DM4** – **Ships Radars**. This DBB mainly covers naval radar systems at TG level, both on the ships and on their associated helicopters. It also includes use of tactical data links on ships at sea.
- **DL2 - Land Training Areas**. Discrete training areas are used around the UK for unit and formation training. There are heavily utilised by visiting units to practice operational roles or rehearse specific operational tasks. Salisbury Plain is the largest training area in UK, and is in constant use. Spectrum demand includes the management of the Plain, and the control of weapons effects simulators. Note that spectrum used by visiting units is covered elsewhere.
- **DL3 - Land Unit in Training**. Superimposed on the training areas are the spectrum demands of the units under training. This particularly addresses the need for multiple Bowman nets (operating at higher power than in-barracks), as well as the full range of tactical equipment, aviation and air support up to Brigade formation level and Divisional Troops.
- **DL4 – Range Radars**. There are some training areas with specific roles, most notably gunnery ranges (e.g. Bovington/Lulworth) where spectrum demand includes range safety radars, communications, and target control systems.
- **DL5 – Land EW**. This DBB covers land EW training.
- **DL6 to DL12 – Special to Land capability (e.g. Artillery, Signals, Aviation)**. A discrete Army unit in one location with additional radio spectrum demand needs relating to its unique role. Specifically Artillery (10 in UK), Signals (8 in UK) and Army Aviation (4 in UK) units are considered because of their additional spectrum demand requirements. In some cases we have associated this demand with barracks, and in other cases training locations. All other unique roles (less the exceptions) fall into the generic Army unit Building Block for a radio spectrum use perspective.
- **DI1 and DI2 – Industry/Research Sites**. A number of discrete research & development and industrial test sites exist across the UK. Spectrum demand is focussed on the specific equipment or capability being developed. An example would be the UAV centre of excellence at Aberporth, West Wales, which is the site of both Defence Science and Technology Facility and Industrial Partners with an expertise in UAVs. Spectrum demand in this location would include management, radio, an operating air field, and numerous data links for telemetry, and collection dissemination.

- **DS3 – Communication Training Establishments**. A number of establishments are dedicated to training recruits and tradesman on equipments that use radio spectrum. They are treated separately because of the density of spectrum demand likely with reference and training systems concentrated in specific locations. An example would be the Royal School of Signals at Blandford where all land communications specialist are trained on transmission equipment from VHF through to SHF
- **DS4 and DS5 – SF and Deterrent**. These DBBs are self-explanatory. By breaking those out we have allowed for subsequent population of the model with highly classified data.

C.4 EXCEPTIONS AND AREAS FOR FURTHER CONSIDERATION

A number of exceptions exist to the Building Blocks identified above, all of which will require a separate assessment of spectrum demand to be included in the final demand totals. Each has a unique spectrum demand based and must be considered individually.

Skynet. Paradigm is under contract to the UK MOD for the Skynet 5 programme. Skynet 5 Services are being used by the UK's armed forces, and are available to government departments and other agencies and organisations that require secure communications. These services are also available to approved defence and other governmental users from overseas countries and multinational organisations, such as NATO.

Reservists. The UK defence spectrum demand will include the training requirements (and some UK operational tasks) for reservists from all three services. The Reserves are a significant element of military capability and largely operate exactly the same equipment as their regular counterparts. The majority of their demand will be captured by training establishments and training area activities however there will be a residual spectrum demand nationally for Reserve units across the country.

Military Aid to Civil Authority/Power. The spectrum demand study has identified that over 1500 Airwave (TETRA type) radios are allocated for use by the military for support to and coordination with emergency services. The spectrum demand for this capability may need to be considered as part of a UK contingency assessment which covers a number of other UK Policing, Security, Border Control and Defence agencies.

Military Aid to Civil Community/National Emergencies. Large scale emergencies and support to the Civil Community (e.g. floods, fireman strike, foot and mouth) where a large scale Military support effort is mounted will invariably require a peak demand of military communications equipment. Such peak demand may intrude significantly on commercial spectrum if ex-crown recognised spectrum access is released to industry. A form of spectrum requisition or intelligent band sharing may be required for such scenarios especially of the emergent commercial use of the band provides critical services in support of such emergency (!).

APPENDIX D STAKEHOLDER AND CONTACT LIST

The key stake holders identified are:

- **CBM J6** - Overall Defence responsibility for spectrum management and policy.
- **DEC ISTAR** - Responsible for procuring some specific battle space spectrum management equipment. Predominantly interested in collection assets (mostly airborne) and the downlink to convey collected data to ground stations.
- **DEC CCII** - Predominantly responsible for network enabled capability, currently focussing on the equipment capability that provides the network itself - Tactical, Operational and Strategic communications systems - voice and data.
- **DEC SP** – Responsible for a number of projects covering counter-terrorism, force protection, and special forces. Quite apart from its sensitivity, this areas is characterised by its relatively near term perspective.
- **HQ FLEET Command** - Command of all Naval assets, Under and Above Water. Focus on conducting training for military tasks, and those military tasks in UK. Capability focussed rather than equipment focussed. The majority of spectrum demand from FLEET originates on board their above water fleet of capital ships. As naval platforms they have a comprehensive and broad range of spectrum using equipment. Naval aviation, Naval Operating Bases, and Naval Dockyards generate specific spectrum demand requirements.
- **HQ LAND Forces** - Command of LAND assets (most of the Field Army and Reserve Forces are represented through LAND). Focussed on training, trials and test and UK operations. The majority of spectrum demand from LAND originates from routine in-barracks training and planned training activities on the major UK military training areas. The use of radio spectrum (between 70MHz and 15GHz) within LAND is largely constrained to Voice/Data Communications, Artillery Surveillance, Ground Based Air Defence, Army Aviation, Tactical Radar, Satellite Communications, and Unmanned Aerial Vehicles.
- **HQ AIR Command** - Command of all AIR assets. Focus on National Air Defence and Intrusion Detection, Air Warfare Training, and Air Navigation and Communications. The majority of spectrum demand from AIR originates from Air Ground Air communications, Air Navigation aids, and the national Air Surveillance and Control System.
- **DE&S** - Specific IPTs as required. Focussed solely on specific equipment's.
- **HQ DSF** - Discrete and unique capability. Focus on training, trials of new capability, and UK CT operations.
- **CSDC** - Command Support Development Centre - including the DSM Centre, and the Land Systems Reference Centre. Focus on communications equipment trials, interoperability and development.
- **Director Doctrine and Concepts** - Focus on the future nature of conflict and evolving doctrine to ensure that UK is positioned to deal.

Main Building

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APPENDIX E ADDITIONAL REFERENCES

- Future Land Operational Concept
  http://www.mod.uk/DefenceInternet/MicroSite/DCDC/OurPublications/Concepts/TheFutureLandOperationalConcept2008.htm
- Global Strategic Trends DCDC 2008
  www.dcdc-strategictrends.org.uk
- Defence Plan June 2008.
  http://www.official-documents.gov.uk/document/cm73/7385/7385.pdf

APPENDIX F FURTHER DETAIL ON MOD RESEARCH AND EQUIPMENT PROGRAMMES

NEC4CC

The Network Enabled Capability for Close Combat (NEC4CC) project is a 3 year research programme for UK MoD's Director of Equipment Capability (Ground Manoeuvre), (DEC(GM)). The programme provides advice to DEC(GM) on how and where NEC can improve military capability in Close Combat.

Early in the NEC4CC programme it was shown that improved network performance and connectivity delivers a number of benefits in Close Combat, specifically:

i. Improved own force situational awareness
ii. The ability to self synchronise
iii. Improvements in the decisions and orders process.

Four Core Enablers of capability have been identified, the first three of which directly improve network performance and connectivity within Close Combat:

iv. Low Latency UHF Soldier radios
v. Bandwidth efficient information management
vi. Geographical/Horizontal interworking
vii. Distributed collaborative planning and tasking.

A wide range of research has been performed within NEC4CC across the domains of Command and control, ISTAR, Logistics, Planning and Human Factors. Many of the interventions and recommendations identified within the research place demands upon the Close Combat communications network. The ability of the network to support these interventions is the subject of a current NEC4CC work package titled "Integrated Network Traffic Analysis" which has yet to report. However, there are some insights that have come out of the work to date.

- The Bowman VHF network at the heart of Close Combat satisfies range requirements but is low bandwidth. The network focuses on voice and is a key constraint on data transfer. Bowman is likely to remain the network over which command is exercised. However, as additional requirements for data transfer emerge, Bowman will not be able to support them, and additional networks will be required.
- The generations of Soldier System radio available now, and in the near future (Gen 2 and 3 radios as described below) will provide simultaneous voice and data capability. They will provide adequate performance in Close Combat up to Company level, but may be range limited in certain scenarios.
- Gen 2 and Gen 3 soldier radios will be capable of supporting additional processes such as richer situational awareness, logistics status reporting and ISTAR product distribution.

Radio	Timeframe	Key Characteristics
Generation 1	Now	Data and voice not simultaneous Voice priority (data blocked by voice) Single channel per network Low data rate (<40kbps)
Generation 2	2008-2012 for TRL 7/8	Simultaneous digital voice and data Multiple voice networks and subnets Medium data rate (<250kbps)
Generation 3	2012-2020 for TRL 7/8	Simultaneous voice and data Mobile ad-hoc networks, multiple modes and channels High data rate (<6Mbps) Packet capability (e.g. voice over IP)

Figure: F-1: NEC4CC classification of future soldier radios

To summarise the above, the NEC4CC programme expects Bowman to be in place for the foreseeable future, used primarily for exercising command. FIST soldier radios will be deployed up to Company level and will be capable of supporting additional data communications relating to logistics and ISTAR information.

The following figure illustrates the conceptual Battlegroup NEC architecture emerging from the NEC4CC research, focusing on Bowman (HCDR, VHF and HF) and FIST (the Soldier System Radio, SSR) as the main networks.

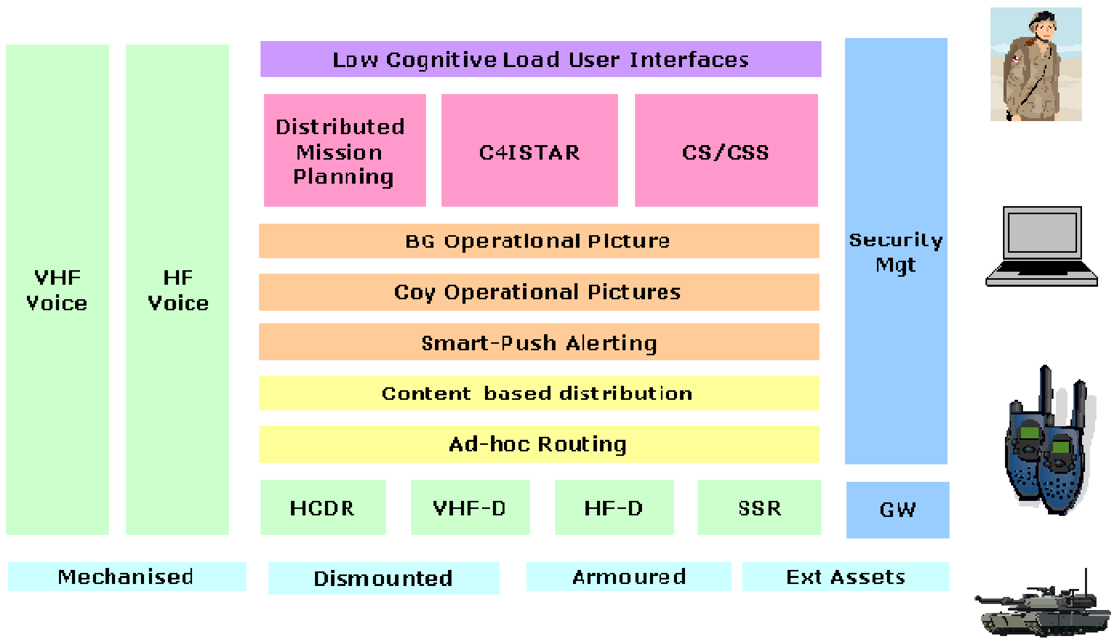

Figure F-2: Battlegroup NEC Architecture

It is acknowledged that the architecture described above, based terrestrial radio networks, may be range limited for certain applications, and bandwidth limited for intensive, high bandwidth information transfer. Therefore, it is expected that dedicated communications networks will emerge to support these new applications.

In addition to research into the ground based tactical networks employed within Close Combat, NEC4CC has conducted a short task investigating the potential impact of airborne networks in CC. The task looked at the impact of airborne nodes on a number of specific scenarios. Key points identified from this task are:

- An SHF (10GHz) air-to-ground relay node would provide point-to-point SA between isolated elements within a convoy. Such technology also provides full motion video imagery to suitably equipped network participants. The airborne node may be UAV based (e.g. Watchkeeper in 2010 timeframe), helicopter based (e.g. a WAH-64 Apache upgrade in 2012 timeframe) or tethered helikite based (considered feasible within the 2012 timeframe).
- A UHF (300MHz) airborne (UAV node, linked to the terrestrial ground-based networks, would provide additional SA capability within a convoy and back to bases.
- Satcom on the move could bring major benefits in isolated CC operations, such as improved SA within convoys. The expectation is that such capability would be provided down to Company level, and that that this would use existing Satcom spectrum. Such technology provided by Skynet 5 is estimated to be deployable within the 2012 timeframe.

FDCC

The Future Dismounted Close Combat (FDCC) project is a 3 year MOD research programme. This programme is developing a set of user requirements for future UK dismounted solider systems.

The programme is conducting research across the five NATO domains of Lethality, C4I (and ISTAR), Survivability, Sustainability and Mobility. All of these domains have the potential to generate information exchange requirements that may or may not be supported by the Dismounted Soldier System (DSS) radio network.

In particular, the C4ISTAR domain has identified a number of research requirements within the FDCC programme that will place demands on the network. These are:

- Location Identification. Demand for increasing location accuracy, especially within GPS-denied areas, will result in the adoption of a suite of location technologies. Ultra Wideband (UWB) location systems will provide a highly accurate location capability, provided the necessary infrastructure can be deployed. It is unlikely that UWB systems will use the full UWB spectrum. The expectation is that such technologies could be deployed by 2011. Simultaneous Location and Mapping (SLAM) technologies, based upon body-worn camera systems, will deliver new a capability for building up three dimensional representations of complex environments. Such representations will be communicated to an HQ, or to other individuals. It is expected that the future solider radio system will be able to support these relatively low bandwidth communications. SLAM technologies are likely to be deployable by 2015.

- Sustainability Networking. The benefits of being able to communicate a range of sustainability information from the individual solider to higher levels of command are being investigated within FDCC. It is expected that a variety of such information, ranging from health status to ammunition levels, will be communicated over the future soldier radio system.
- Personal Area Networks (PANs). The demand for helmet- and weapon-mounted devices, coupled with a desire that neither helmet nor weapon should be tethered to the individual will see introduction of PANs in dismounted close combat. The timeframe for these within DCC is not clear. Issues of EMC, security, reliability and RF signature need to be addressed before PANs are widely adopted.
- Electronic Countermeasures (ECM). Although identified as a research requirement within FDCC, the problem of interoperability with ECM equipment is out of scope. However, it must be noted that any future devices making use of the electromagnetic spectrum will need to demonstrate that they can operate alongside ECM force protection equipment.
- Collaborative Engagement. Sensor-to-shooter and collaborative engagement are two important concepts within the future soldier system and are seen as an essential capability. This piece of research is yet to start within FDCC, but is will certainly place demands on the communications network.

The items above are provided to highlight the perceived future demand for network bandwidth within the DSS. It should be noted that the specific bandwidths required will not be identified within FDCC. FDCC will generate requirements for the use of the network. It is the responsibility of programmes such as NEC4CC to recommend best use of the available bandwidth within close combat.

FIST

The FIST programme has not placed any restrictions on the band within which the future FIST C4I radios can operate. Choice of band is likely to be as much about compatibility with ECM and force protection equipment as it is about performance.

Nevertheless, it is our view that the likely FIST solution will be drawn from radios operating anywhere in the 30MHz to 2.7GHz, and possibly up to 4.9GHz.

FIST increment 1 is due to achieve IOC in 2010. FIST increment 2 is due to achieve IOC in 2015. From a C4I perspective, increment two is largely focused on achieving Bowman and vehicle integration. Therefore, it is likely (although not certain), that radios procured for FIST inc 1will be the same as those used in FIST inc 2, and that whatever is procured for 2010 will still be in use in the 2020 timeframe.

Examples of potential FIST radios are given in the table below (this is not exhaustive, merely illustrative).

Manufacturer	Radio	Bands of operation	Power	Notes
SFF JTRS Radios	SFF-I	225 – 450 MHz	5W	Soldier radio for the US Army's FCS programme
	SFF-B	30 – 2500 MHz	5W	Soldier 'leader' radio for the US Army's FCS programme
Raytheon	DH500	22 5MHz – 2 GHz	4W	Low power, standalone version of Raytheon EPLRS radio
Harris	RF-300S-TR	225 – 470 MHz		The US SPR variant of the RF-7800S
	RF-7800S	350 – 450 MHz		
ITT	Soldier Radio	30 MHz – 2.7 GHz	5W	
	Spearnet	1.2 GHz, 2.4 GHz, 4.9 GHz		
ST@R	Mille-S	325 – 470 MHz		Demonstrated to Thales in Feb 08
Cobham	Eagle	2.4 GHz	100mW	Up to 5 hop MANet radio.
Kongsberg	SR600	225-400 MHz	10mW – 1W	Developed from Kongsberg's TACLAN radio

Table 9-1: Examples of Potential FIST C4I Radios

Bowman

We are unaware of any plans to replace Bowman, and expect its use to continue through to the 2020 timeframe and beyond. A range of improvements is being considered for the BCIP 6 release. However, these focus on areas such as tools, applications and interoperability. We are unaware of any plans to change the spectrum allocation used by Bowman, although increased use is likely, especially within the band used by HCDR.

Within the Battlegroup, we expect to see Bowman interoperability with FALCON, and the use of FALCON extending further into the Battlegroup – down to Company level and possible Platoon. We expect to see Bowman interoperability with FIST in the 2015 timeframe, with the FIST network extending up to Platoon and Company level.

Enabling Secure Information Infrastructure (ESII)

The aim of this research programme is to investigate how NEC benefits can be delivered quickly and cost effectively. Task 1 reported in September 2007 and identified 5 prioritised capability gap areas:

- Individual addressable battlefield communications
- Joint fires coordination
- Distribution of ISTAR products
- Over the horizon communications for disadvantaged maritime users
- Blue force positional information.

Solutions to these were studied, and the following major components were identified that demand spectrum usage:

- Personal satcom. e.g. Iridium. This would use existing services and not require any new spectrum allocation. Achievable now, with a new satellite constellation offering greater capacity operational in 2012.
- Exploitation of civil cellular technologies and service providers (e.g. 3G, TETRA). Technology available, but gateways into military networks may delay introduction.
- Gateways into tactical data links
- Theatre broadcast technologies. If using an existing satellite service is used to achieve this, then no new spectrum is required.
- Airborne communications relays. May require new spectrum.
- Enhanced Bowman HCDR and FALCON. Timeframe of 2012. This may require additional spectrum in the UHF band.
- Joint Tactical Radio System (JTRS) Wideband Networking Waveform (WNW). Timeframe of 2012. Would require new spectrum, likely to be in UHF band, for WNW radios (UHF bandwidths up to 30MHz depending upon waveform).
- Enhanced Maritime Tactical Network Command and Control (MTNC2). The concept is that MTNC2 (2012 timeframe) is extended by linking in with civilian Satcom services such as Inmarsat, by linking in with other HF and UHF networks.
- Extend the life of Ptarmigan Single Channel Radio Access (SCRA)
- Extend FALCON to provide services down to BG HQ.

Competition of Ideas

In July 2007, Plextek won a Competition of Ideas (CoI) project to demonstrate an adhoc communications system for use in convoys. The aim of the system is to situational awareness, text message communication and asset tracking within a logistics convoy. The demonstrated system used a PEARL Ultra Narrowband Radio (UNB) operating at 868MHz, 0.5W transmit power.

Such a concept appears to have been well received within areas of the MoD such as DEC(ELS) and has been successfully trialled as CSS TDU. Therefore the use of such dedicated systems to provide SA to non-Bowman equipped vehicles may be adopted.

Unmanned Aircraft

Demand for spectrum for unmanned aircraft is expected to grow significantly, especially from small Category 1,2 and 3 UAs (i.e. up to 150kg).

In the near term, out to 2010, increased use of small UAs for reconnaissance and as a communications relay is expected. Beyond 2010, use for SIGINT collection is anticipated.

UA communications can be generally split into two parts.

- The first covers requirements for command and control, sense and avoid and air traffic control (ATC). The requirement for command and control could comfortably be satisfied by a 30kbps downlink and 15kbps uplink.[31] The requirement for sense and avoid may be for a few hundred kbps depending upon the technology used. The air traffic control channel for UAs will need to conform to international interoperability standards for ATC, and is therefore likely to be a VHF voice channel relay mounted on the UA to enable ATC to communicate with the UA operator.
- The second is the communication requirement for the UA payload. For payload communications (frequently full motion video or similar), high rate data and low latency links are required either to the ground or to a satellite. Expect a single UA to require bandwidth >10Mbps for many applications.

Ku-band is the normal choice for high bandwidth satellite data links. Ka and X-band are also being adopted as pressure on Ku-band increases.

The Rover 4 terminal, from L3 Communications, is widely used to receive imagery from aircraft on current operations operates in the following bands:

- 14.4GHz – 15.35GHz, 10.71Mbps
- 5.25GHz – 5.85GHz, 455Kbps
- 4.40GHz – 5.85GHz, 466kbps
- 4.40GHz – 5.85GHz, analogue
- 2.3GHz - 2.5GHz, analogue
- 1.71 – 1.85GHz, analogue.

The Rover 5 transceiver terminal, due to be released this year is expected to be widely used. It offers up to 44.73Mbps downlink, and includes an uplink. In general, increased use of such terminals due to proliferation of UAs over the next 20 years can be expected.

Large UAs, above 150kg, are expected to have additional capability requiring new communications links. In the 2015+ time period UA to UA in flight refuelling is expected, requiring high bandwidth low latency communication between UAs. In the 2020+ timeframe use of UAs for surveillance and for battle management is expected.

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[31] Small UAV Command, Control and Communication Issues. Joseph Barnard. IET Seminar on Communicating with UAVs, 5 Dec 2007.

Overview of Existing Radars

There are a large number of military and civil radar systems in operation in the UK covering Air Traffic Control (ATC), Air Defence (AD), Meteorological (Met Office) and other roles. The principal aim of radar is to detect, locate and in most cases track ground-based and airborne objects[32]. Individual requirements vary between these radars, e.g. coverage, size of objects to be detected, scan rate. These requirements drive the design and implementation of radar systems.

The radar systems in the UK principally utilise the radio bands L-band (approx. 1GHz) and S-band (3GHz). A number of X-band (10GHz) radars exist, principally for short-range tracking and for airport surveillance.

Most of the radar transmitters in the UK utilise Magnetron or Travelling Wave Tube (TWT) technology with some solid-state based radars appearing. Magnetron-based radars are generally used in marine radars.

Current radar systems use rectangular or near-rectangular pulses because these are the most efficient way of delivering maximum energy on target during the pulse duration. Using rectangular pulses allows high-power transmitters to be run into saturation without fear of distorting the pulse whilst providing the maximum power efficiency. In more modern civil ATC radar, solid-state devices are being introduced.

Range resolution is obtained through simple, unmodulated short pulses or by modulation of long pulses, by linear or non-linear variation of amplitude, frequency or phase during the pulse duration. Long, modulated pulses, used in ATC radars, have the disadvantage of a long eclipsed range, i.e. the radar receiver must be switched off whilst the transmitter is transmitting. This entails loss of short range coverage. To mitigate this, most such radars employ a short pulse waveform to detect short range targets.

Air Defence Radars

There are eight AD radars in the UK. These radars form part of the UK Air Surveillance and Control System (ASACS), and operate at either L-band (Type 92; 1,215-1,400MHz) or E/F-band (Type 93 and Type 101; 2-4GHz).

[32] Weather radars have a different function, that of detecting water droplets in the lower atmosphere to estimate rainfall.

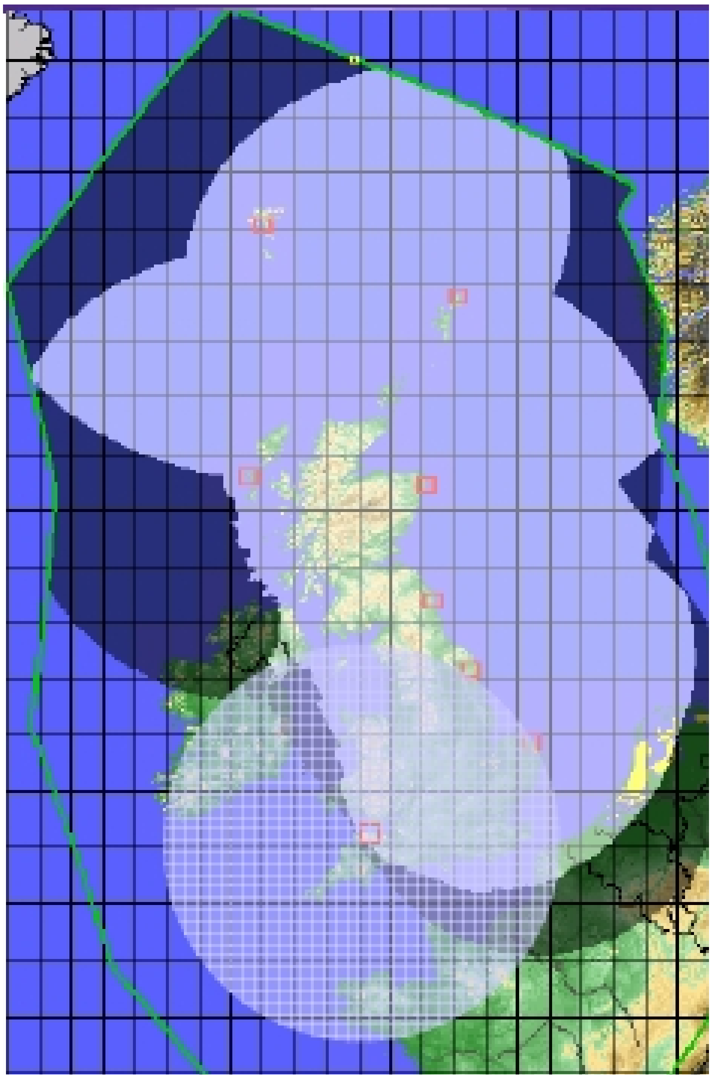

Figure G-1: Air Defence radar locations

Air Defence radars are principally used for long range (approximately 250-500km) 3D surveillance and tracking of air objects in UK airspace up to approximately 90,000ft altitude. They employ sophisticated processing, such as clutter mapping, pulse compression and coherent (i.e. Doppler) processing to be able to detect, track and discriminate objects. Due to the high elevation (high altitude) coverage of these radars the objects tend to be aircraft.

The four Type 93 radars are planned to be upgraded over the next few years, under the T93 Capability Replacement Programme. These will be replaced by the BAE Systems Insyte Commander SL, designated Type 102. This programme will also involve planned upgrade of the Type 101 (Commander) radars. Unlike the Type 101 radar, the Commander SL radar utilises solid state technology. Other improvements include advanced digital tracking. The service life of these radars is expected to be approximately 20 to 25 years.

Civilian ATC Radars and NATS En-route Radars

ATC radars are principally located at civilian airports and larger aerodromes and are used to monitor terminal manoeuvring operations (approach, take-off and landing). Primary Surveillance Radar (PSR) may be augmented by Secondary Surveillance Radar (SSR) capability to provide a robust system for tracking aircraft. The PSRs operate at S-Band (2700-2900MHz), although there are several short-range X band radars for airport surveillance. The S-Band PSRs operate out to approximately 60nmi to 80nmi. SSR radars operate at L band (1030MHz and 1090MHz). Many airfields will also have some form of instrument approach facility, such as military Precision Approach Radar (PAR) operating at 3GHz or Instrument Landing System (comprising some or all of a VHF localizer beam, UHF glide-slope and UHF distance measuring equipment). The latter two are short range.

PSRs have some form of terrain clutter cancellation, through Moving Target Indication (MTI) or Moving Target Detection (MTD) techniques. Pulse compression is used in the majority of these radars to provide the required range resolution for discriminating between closely-spaced aircraft (minimum aircraft spacing requirement is dictated by the CAA).

There are 55 S-band frequencies assigned to UK civil ATC radar, of which 12 are used by more than one radar. Typically the bandwidths of these assignments (at the -20dB points) vary between about 2.4MHz and 10MHz. There is a significant degree of overlap in used frequencies between the different radars. However, Pulse Repetition Frequency (PRF) is used as a discriminator between the radars.

In addition to these, there are approximately 20 medium-range and long-range L and S-band PSRs in the NATS network supporting en-route operation of commercial and military aircraft over UK airspace.

There are approximately 34 L-band frequencies assigned to UK civil ATC radar, and four of these frequencies have more than one radar assigned to them. The bandwidths of these assignments (at the -20dB points) vary between 3.9MHz and 16.7MHz. Most radars require more than one frequency in order to enable frequency diversity or multi-pulse operation.

Military ATC Radars

The military ATC service is co-ordinated with the civilian ATC network run by NATS. There are some 80+ military ATC radars in the UK, typically S-Band BAE Systems Watchman radars. Due to the nature of military operations a number of these radars are mobile. These systems are generally set up with classified system parameter configurations, but generally operate like their civilian counterpart.

Met Office Weather Radars

There are approximately 20 meteorological office radars operating in C band (5.35GHz) in the UK. They are employed for the detection of rainfall, snow and hail storms over distances of up to 255km, although 75km is more typical.

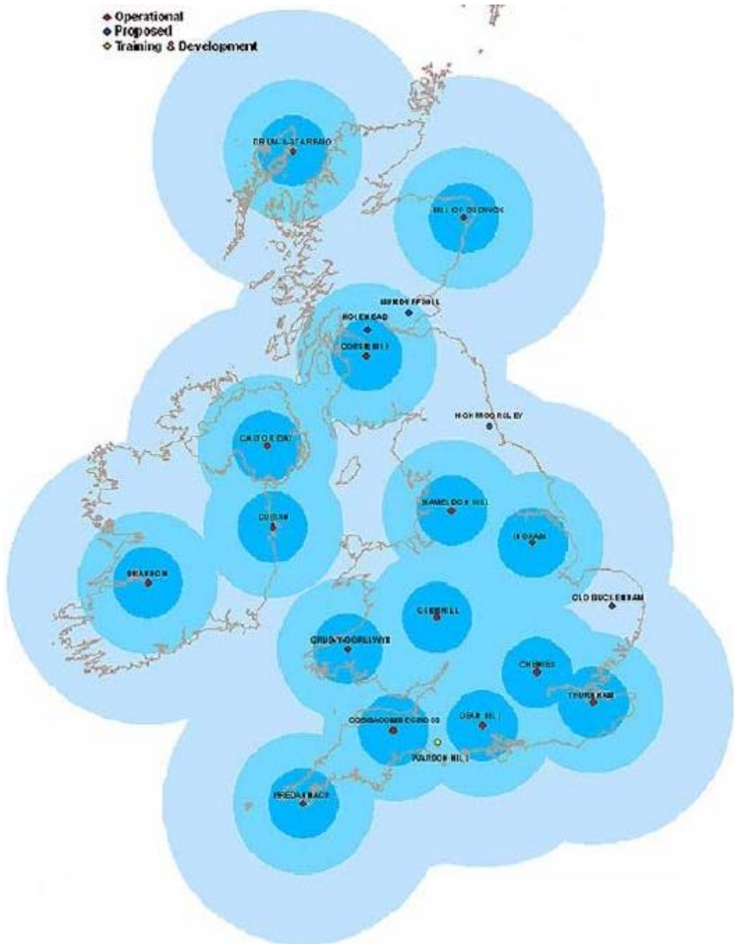

Figure G-2: Met Office weather radar locations

A number of weather radars are Doppler radars, as opposed to incoherent, and can measure direction and radial velocity of raindrops.

The Met Office also operates approximately five wind profilers in the UK, principally looking at vertical or near vertical beam pointing angles. They operate at L-band.

Classified

APPENDIX I   FUTURE LOCATION ASSUMPTIONS

This Appendix outlines the assumptions on changes to the defence locations within UK in the 2015 and 2027 timeframes to be used for modelling within the Defence Spectrum Demand Study.

Whilst based on the best estimates of the relevant staffs, and reflecting the Defence Estates Development Plan 2008 it should not be viewed as a funded position, and merely reflects a "most likely" position to allow spectrum demand to be modelled.

I.1 SERVICES' ESTATE STRATEGIES

Royal Navy

The Royal Navy's operational and training estate is generally of a size and in a location which is fit for task and there are only relatively minor changes planned.

2015

- HQ Fleet's highest priority is to establish a site for the newly formed 24 (Cdo) Regt RE. It is assumed that this has been stood up at Chivenor. Given the priority, it is assumed that a solution will have been found, and this will have taken place by 2015.

There are 2 other options currently being considered which might have a minor impact, but given the degree of uncertainty, these have not been assumed in the 2015 model.

- There is a PFI currently being established to replace the current MoD/MCA Search and Rescue capability. This may have an impact on RNAS Prestwick where the current lease is due to expire in 2018.
- There are several studies/proposals being undertaken looking at co-location of Royal Marine facilities, including Landing Craft Relocation, possibly to Devonport Dockyard

2027

- HMS SULTAN, which is now part of the Defence College of Electrical and Mechanical Engineering, is due to close as part of the Defence Training Review, and its functions re-located to RAF St Athen in 2017. This has been assumed in the 2027 model.

The Army

The Army has the largest and most complex estate of the 3 Services, and its long term plans are driven by a number of factors, the most significant of which are:

- The Supergarrison concept which seeks to bring formation coherence and a better quality of life for soldiers and their families by providing better facilities through economies of scale, and reduced family turbulence throughout a soldier's career.
- The drawdown of numbers based in Germany; current PPSG assumptions are that troops may be based in Germany until 2035, and that the pace of the drawdown will be driven by the availability of suitable locations in UK, and the funding to carry out the required works.
- An improved national footprint, from a regular Army heavily centred on Southern England towards a better presence in Central and Northern England.

However these strategic goals will be tempered by the realities of where real estate might be available at little or no cost to Defence (typically through the release of RAF stations) and the availability of funds. Given the cost of a major unit relocation (up to £500M including single living accommodation) implementation is likely to be relatively slow and based on opportunities as they arise.

Detailed changes to the Army estate locations used in the model are included in the following chapter. However the major assumptions are as follows:

2015

- Project BARONA will have moved HQ ARRC, 1 Sig Bde, and 102 Log Bde from Germany to UK.
- HQ Land Forces will have moved to Andover under Project HYPERION
- There will be some rationalisation of AAC basing under Project BELVEDERE, a Joint Helicopter Command study looking at the rationalisation of the Rotary wing estate. For the purpose of this study it is assumed that RAF Odiham and Benson will close and subsequently be available for Army use, although actual occupancy in this timeframe will be constrained by the Non Equipment Investment Plan.
- Moves of some units to Blandford, enabled by the transfer of instructional functions to St Athen under DTR.

2027

- For the purposes of this study the major assumption is that one of the 2 armoured brigades will have moved from Germany to a supergarrison in the West Midlands based on Tern Hill, Stafford, and RAF Cosford.

Royal Air Force

The RAF's strategic basing plan is primarily driven by the need to make efficiency savings by reducing the number of stations. The overarching basing strategy is that the number of small units are minimised and that maximum utility is made of core Main Operating Bases (MOBs). The nature and timings of these rationalisations are closely linked to the introduction into, or out of service date, of certain aircraft types. Further detail is listed in Chapter 3, but the following are the primary assumptions:

2015

- Project BELVEDERE is considering the rationalisation of the Joint Helicopter Command Estate. For the purpose of this study it assumed that all RAF support helicopters will consolidate at RAF Lynham, leading to the closure of RAF Odiham and Benson. (It is assumed that these will subsequently be available for Army use, although actual occupancy in this timeframe will be constrained by the Non Equipment Investment Plan.)
- RAF Insworth will remain closed and will be available for Army use by HQ ARRC.
- RAF Cosford will have closed under DTR, and will be available for Army use by 1 Sig Bde and 102 Log Bde.

2027

- Continued use of RAF Cottesmore has not been confirmed following the out of service date of Harrier GR9 in 2018, and may be available for Army use. However given the uncertainty, and the fact that it is unlikely that there will be any Army occupancy in this timeframe due to constraints on the Non Equipment Investment Plan, for the purposes of this study it is assumed that it remains open as an operating base.

- Other stations may have, or be about to be closed, but given the current lack of clarity, these have not been included in the model.

Central TLB

There is only one move of tri-service or Defence locations that is considered significant.

- The establishment by 2017 of a major training centre at St Athen under DTR, permitting the closure or reuse of a number of single service sites.

I.2 DETAILED LOCATION ASSUMPTIONS

The following detailed assumptions will be used in modelling. It should be noted that:

- Many of these changes are still subject to decision making and/or funding. They are not authoritative, but should be considered a "best guess" for modelling purposes.
- "Completed" dates refer to whether the change is likely to have been completed by the 2 snap-shot times being modelled, ie 2015 and 2027, not individual activity dates.

Location	Key Radiation Changes	Completed	Remarks
Chivenor	Plus 1 x major unit	2015	24 Cdo Regt RE
Woolwich	Cease to be RA location	2015	RA units assumed to have radiation demand (eg MSTAR) not found in other major units. 1 x PD battalion plus King's Tp RHA
St Johns Wood	Close	2015	King's Tp RHA
Hounslow	Close	2015	Assume PD battalion move to Woolwich
Lichfield	Base protection (security) only	2015	Recruit training function amalgamates with Pirbright. HQs Defence Medical Education and Training Agency and Royal Centre for Defence Medicine together with the Defence Medical Services Training Centre
Andover	Overall no change	2015	DE&S vacates, Land Forces occupy under HYPERION
Wilton	Close	2015	Closes under HYPERION
Upavon	Overall no change	2015	Base security only. Some use may be still required under HYPERION
Brawdy	Close	2015	14 Sig Regt relocates to Blandford
Blandford	Comms training ceases. 2 x R SIGNALS major units added	2015	14 Sig Regt (from Brawdy) and 10 Sig Regt from dispersed locations
Hullavington	Close	2027	9 SUP Regt RLC move to Aldershot
Stafford	Plus 6 major units incl 1 x Sig and 1 x RA	2027	West Midland Supergarrison for bde from Germany
Abingdon	Increase by 1 major unit	2027	
Dishforth	Close airfield, retain as major unit location	2015	Airfield closes under BELVEDERE. 12 LSR to move to Catterick

Location	Key Radiation Changes	Completed	Remarks
Arborfield	Close	2015	DTR rationalisation
Bicester	Increase by 2 major units, incl 1 x EOD	2027	11 Regt RLC plus minor units
Boredon	Close	2015	DTR rationalisation
Canterbury	Close	2027	Bn move to Colchester area
Colchester	Increase by 1 major unit	2027	Vice Canterbury
Deepcut	Close	2015	DTR rationalisation
Innesworth	Base protection only	2015	Changes from RAF (closed) to HQ ARRC
Cosford	Add 7 major units, incl 5 signals units	2015	102 Log Bde plus 1 Sig Bde
Lynham	Change from FW to 10 x SH sqns	2015	Under project BELVEDERE
Benson	No change	2015	Assume rerolled for Army RW use under BELVEDERE
Odiham	Base protection (security) only	2015	Assume retained for possible future Army use
Cottesmore	No change	2027	May be retained as operating base. Otherwise retained for possible future Army use
Leeming	Airfield remains open No FJ based UAV base	2015	Airfield remains open after Tornado F3 withdrawn. Site for REAPER post Afghanistan 90 SU Base
Scampton	Airfield role ceases Close	2015 2027	Red Arrows relocation. ASACS continues ASACS relocated to RAF Conningsby
Brize Norton	Up to 10 FW sqns	2027	C17, C130, A400, Tristar and VC-10 base
Mareham	Base protection (security) only	2027	Assume retained for possible future Army use after GR4 OSD
Uxbridge	Close	2015	
St Athen	Airfield closes, major unit remains, 2 comms trg schools colocate	2027	DTR rationalisation

APPENDIX J GLOSSARY

AA	Air-Air
AD	Air Defence
AGA	Air-Ground-Air
AIP	Administered Incentive Pricing
ASACS	Air Surveillance And Control System
ATC	Air Traffic Control
BCIPs	Bowman Combat and Information Platform
BMEWS	Ballistic Missile Early Warning System
BOI	Balance of Investment
C4I	Command, Control, Communications, Computers and Intelligence
CADMID	Concept, Assessment, Development, Manufacturing, In-service, Disposal
CBRN	Chemical, Biological, Radiological and Nuclear
C-IED	Counter-Improvised Explosive Devices
COEIA	Combined Operational Effectiveness and Investment Appraisals
COTS	Commercial Off-The-Shelf
DBB	Defence Building Blocks
DEC	Director of Equipment Capability
DTIC	Defence Technology and Innovation Centre
ECM	Electronic Counter-Measures
EMC	Electro-Magnetic Compatibility
EOD	Explosive Ordnance Disposal
EP	Equipment Programme
EW	Electronic Warfare
FDCC	Future Dismounted Close Combat
FIST	Future Integrated Soldier System
HCDR	High Capacity Data Radio
HF	High Frequency
IED	Improvised Explosive Devices
IPT	Integrated Project Team
LPD	Low Probability of Detection
LPI	Low Probability of Intercept
LRB	Long-Range Bearer
LRR	Long Range Radar
MRR	Medium Range Radar

NATO	North Atlantic Treaty Organisation
NEC	Network Enabled Capability
PBSMS	Pilot Battlespace Spectrum Management System
PMR	Private Mobile Radio
RAO	Research Acquisition Organisation
SCRA	Single Channel Radio Access
SKE	Station Keeping Equipment
UAV	Unarmed Airborne Vehicle(s)
UCAV	Unarmed Combat Airborne Vehicle(s)
UWB	Utra Wide Band